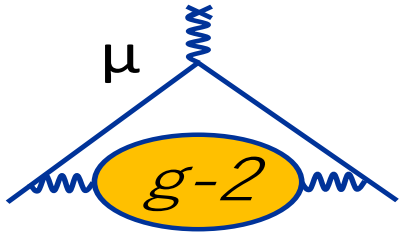
Fermilab

Magnetometer measurement for g-2 experiment

FERMILAB-SLIDES-23-0431-STUDENT

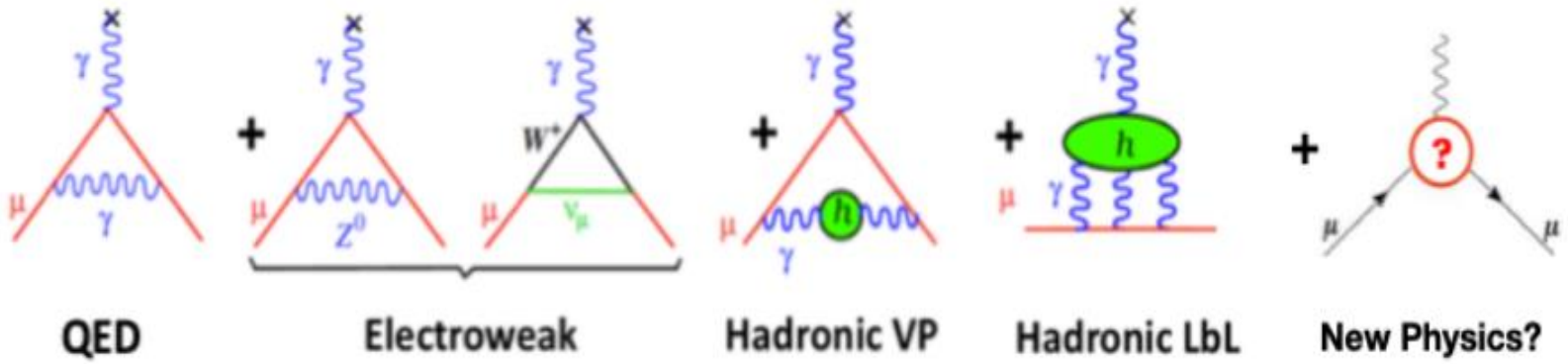
Magnetometer measurement for g-2 experiment

Nicolò Rossolino



Introduction to Muon g-2

- $\vec{\mu} = g\frac{q}{2m}\vec{S}$
- $a_\mu = \frac{g-2}{2}$



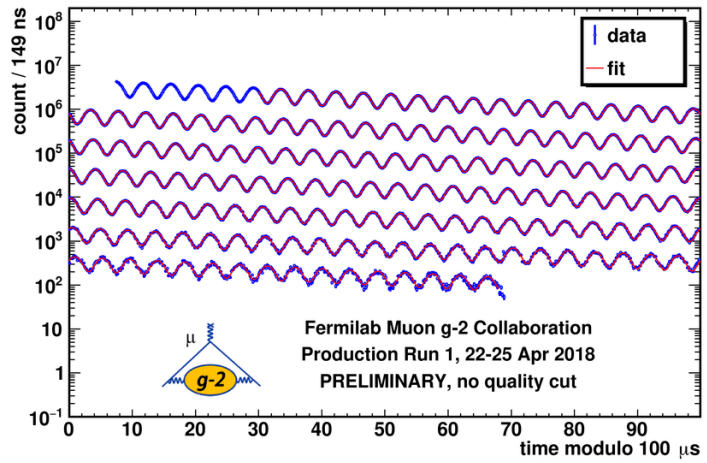
Dirac equation: $g = 2$ → QFT: $\sim 10^{-3}$ shift → BSM: What we are searching!

Master formula for analysis

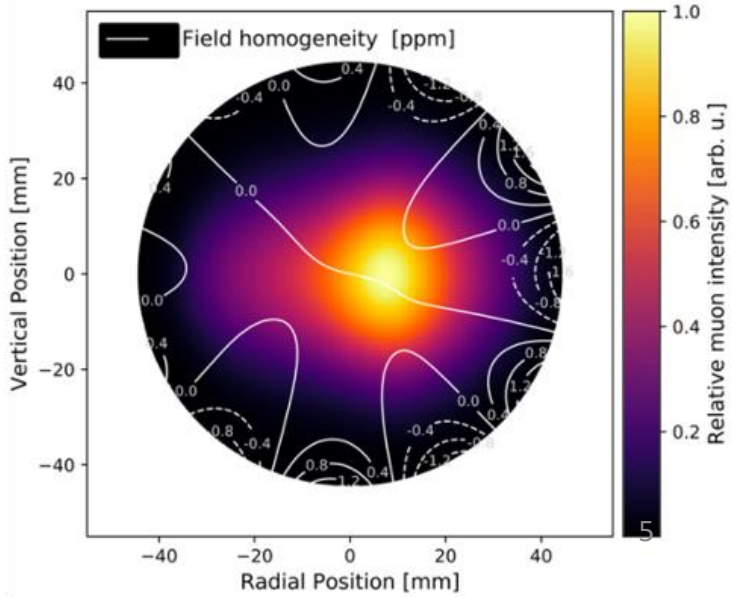
$$R_\mu = \left(\frac{f_{clock} \cdot \omega_a^{meas} \cdot (1 + C_e + C_p + C_{ml} + C_{pa})}{f_{calib} \cdot \omega_p'(x, y, \phi) \otimes M(x, y, \phi) \cdot (1 + B_k + B_q)} \right)$$

ω_a — beam dynamics corrections

$\tilde{\omega}_p'(T_r)$ — field corrections

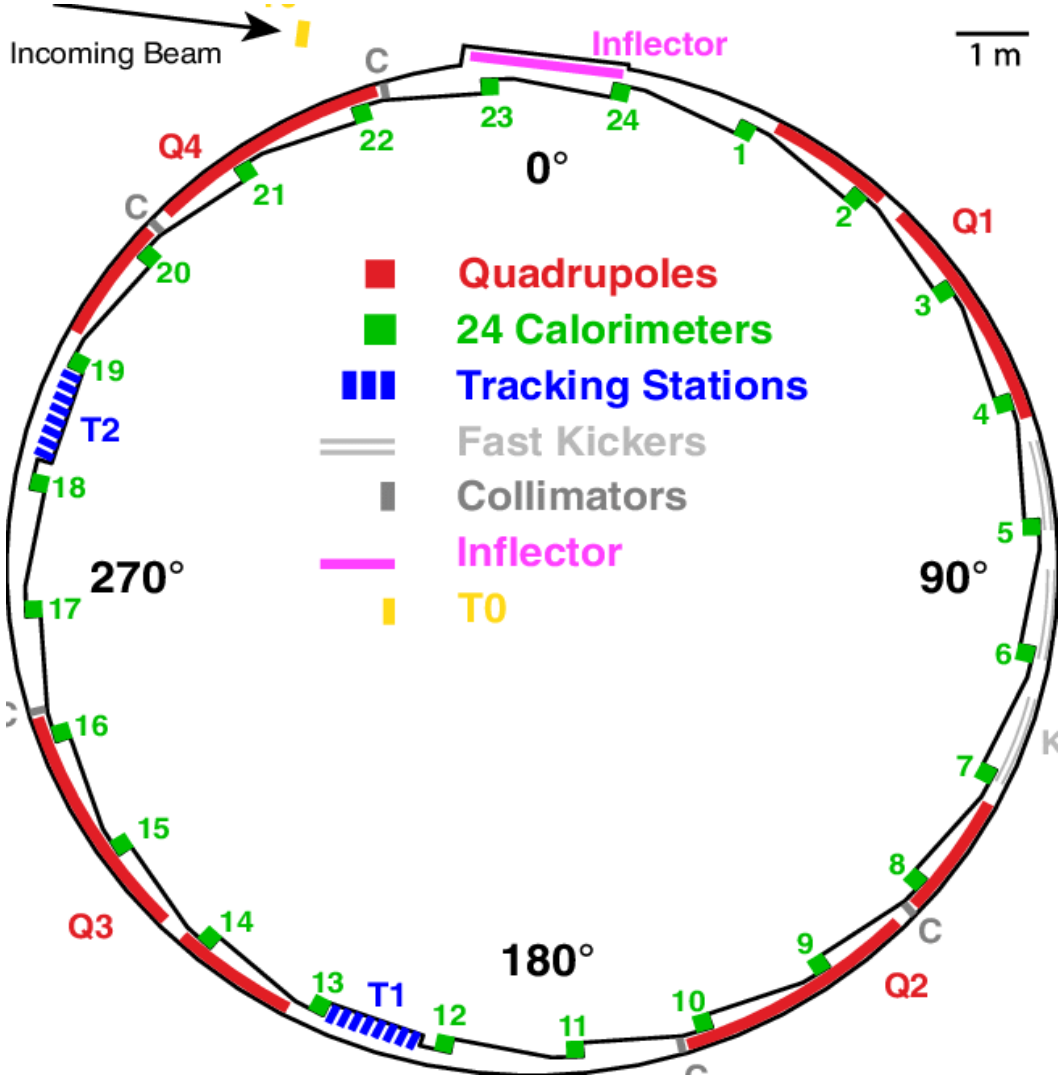


My work focuses on B_k which is the transient field from eddy currents in kickers and the measurment of the kick pulse



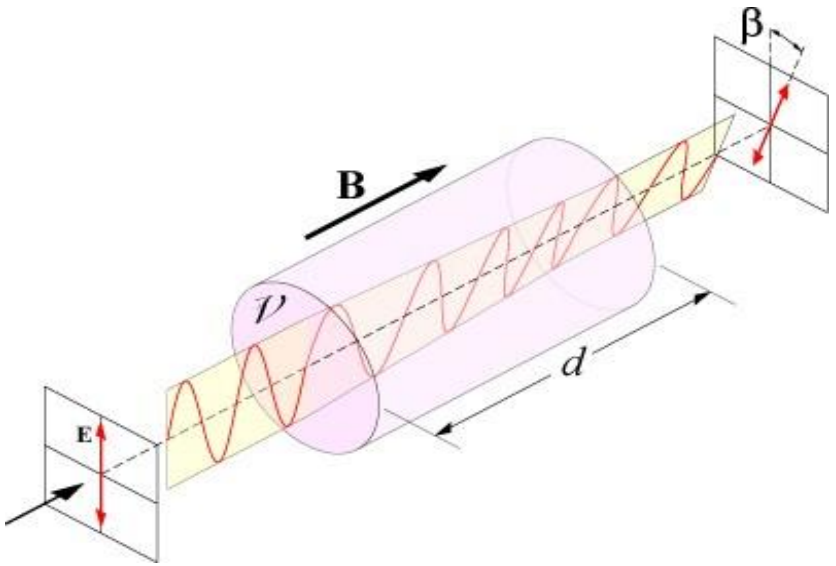
Magnetic Kicker

- g-2 uses three magnetic kickers to create a vertical magnetic field to deflect the beam into a centered stable orbit (magic radius)
- The kicks are magnetic pulses of about 200 Gauss
- The presence of eddy currents causes the kicker transient magnetic field, an effect of about 1-2 mGauss that extends in the measurement time window
- We measured the pulse of the kicks and the eddy currents with a **magnetometer** based on the Farady effect



Faraday Rotation

Farady effect is the rotation of the light linear polarization into some particular dielectrict crystals when they are subjected to magnetic field

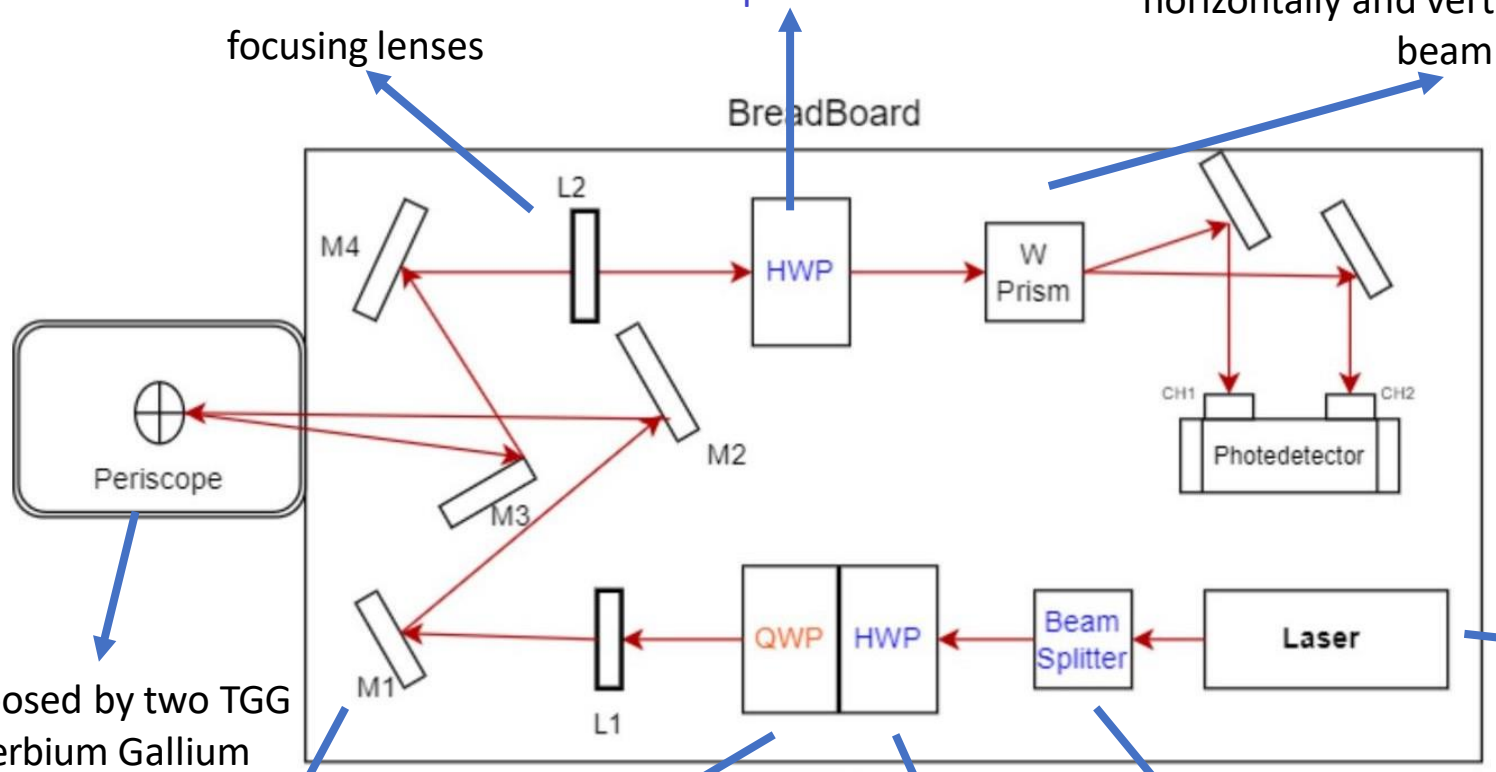


Farady rotation is used to measure the kicker transient magnetic field, since the variation of the magnetic field is proportional to the rotation of the polarization of a laser beam

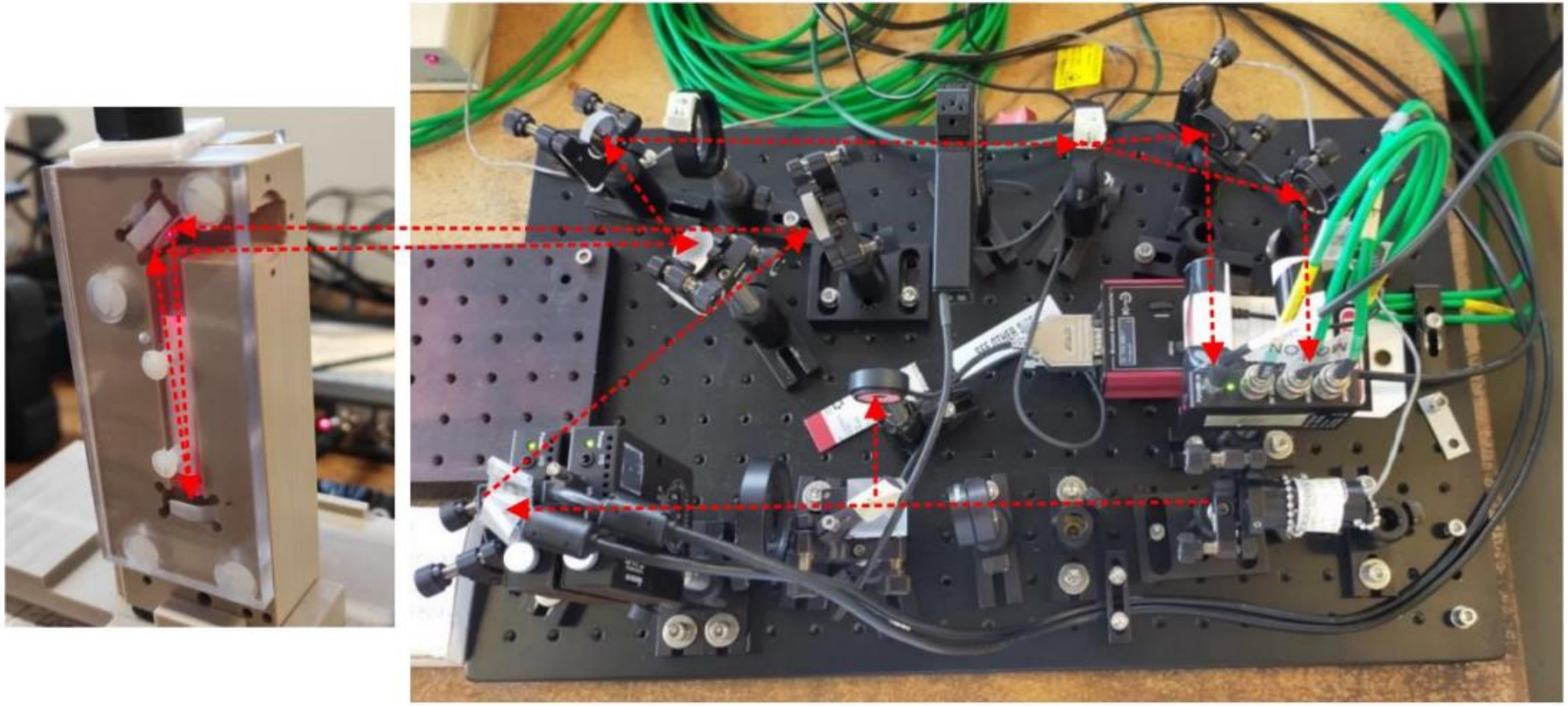
$$\beta = V \cdot B \cdot d$$

Magnetometer experimental setup

The pirinciple is to study the Faraday rotation sending a laser ray in a TGG Verdet crystal

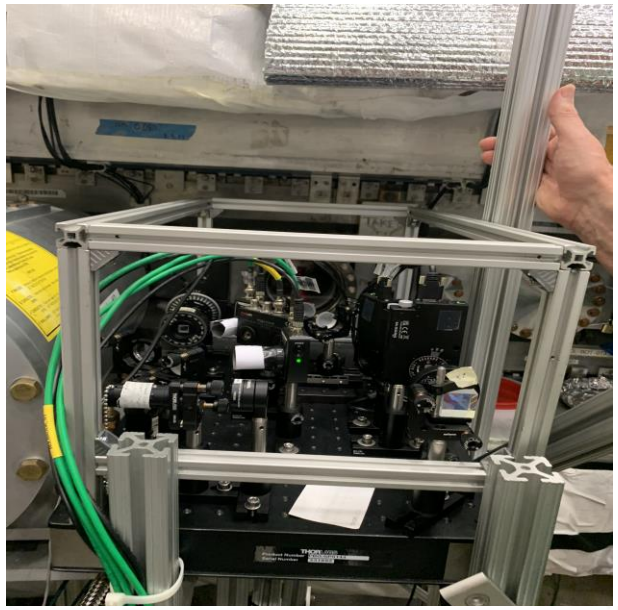


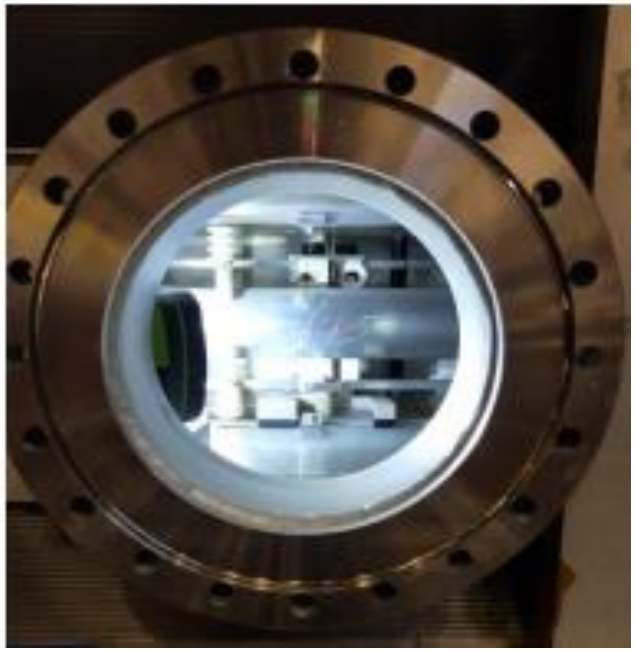
Magnetometer Pictures

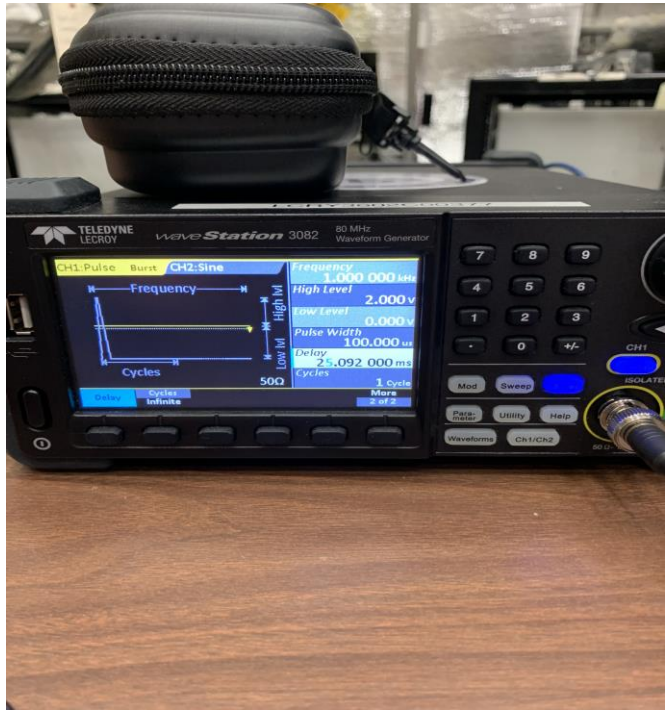


Laser beam path on the breadbord and into the periscope

Into the ring







The main goals of my project are:

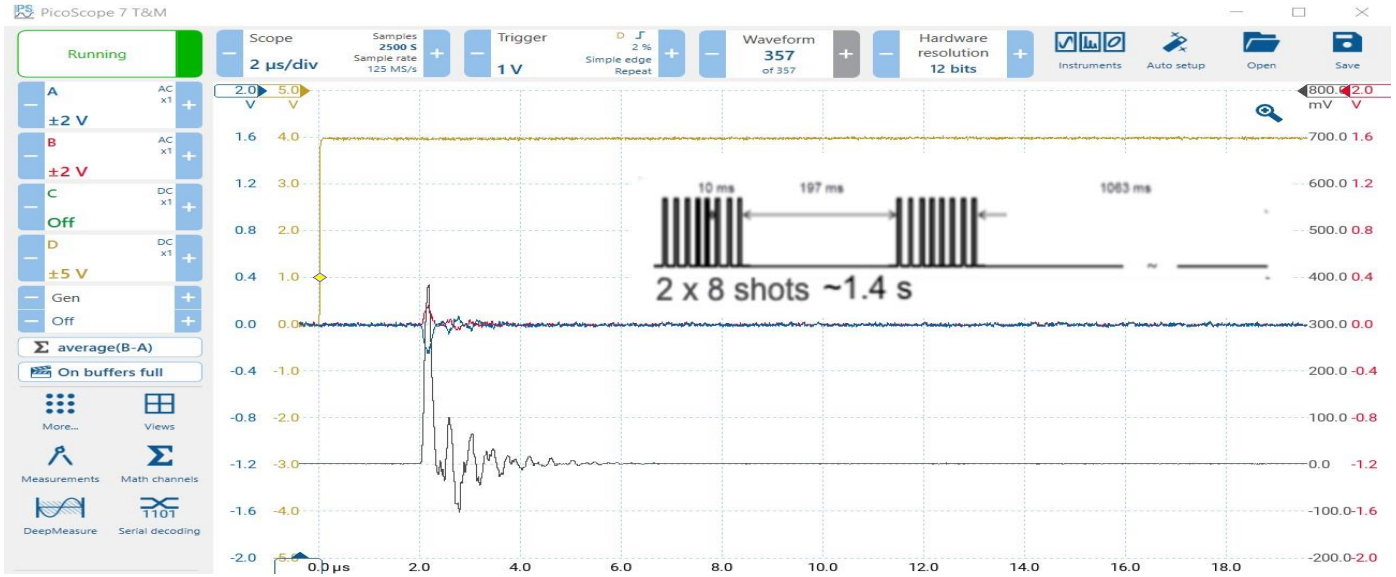
- **Install** the breadboard inside the ring in the kicker 3 region
- Measure the pulse of the **main kicks** and comparing them with each others
- Take measures at two **different radial distances**
- Measure the **eddy currents** contributions
- Add the new pulse measurement in the **simulation**

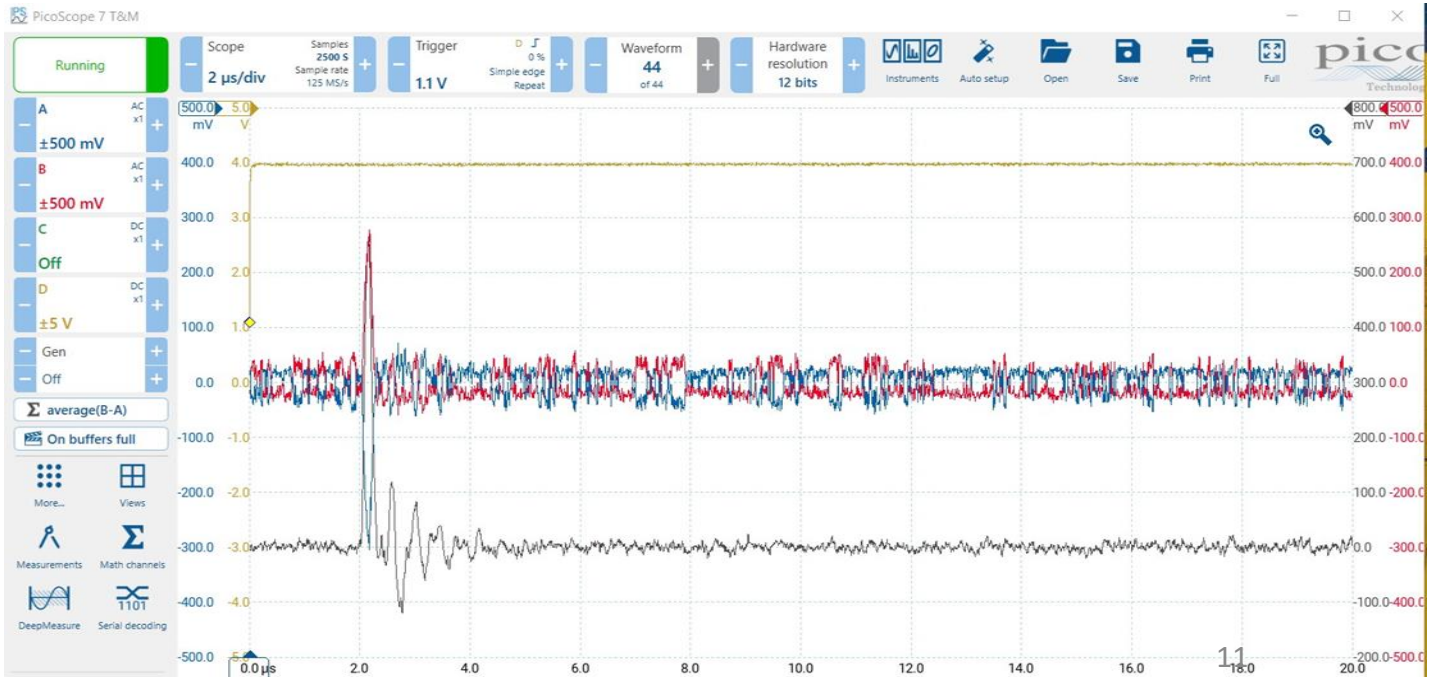
DAQ Setup

Trigger mimics the experiment:

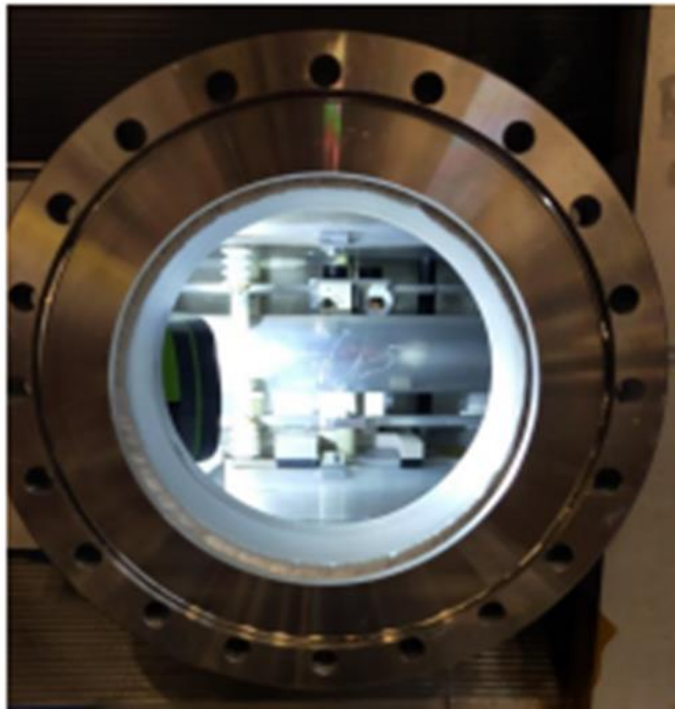
- Two groups of bunches each separated by 200ms
- Each group with 8 kicks separated by 10ms
- Data were recorded in 20us interval and 4ns sampling steps

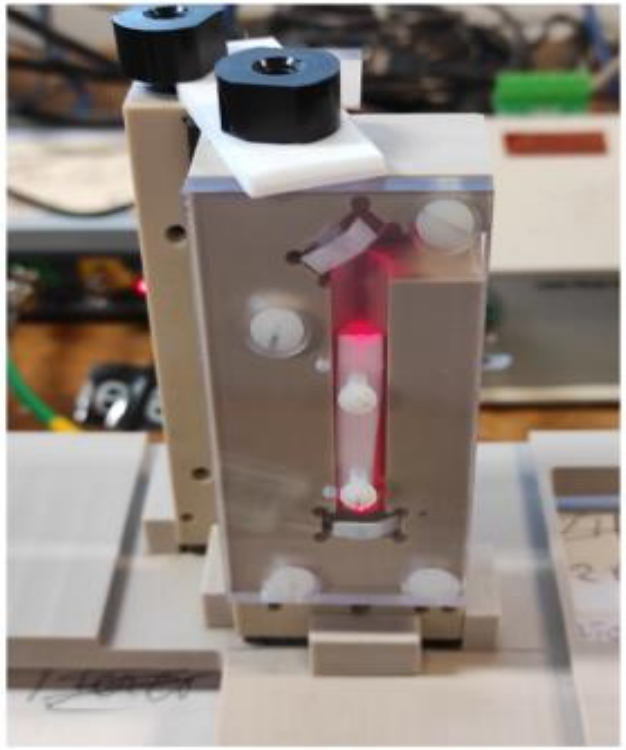
To acquire the full kick pulse we use a fast diode model PDA10A2





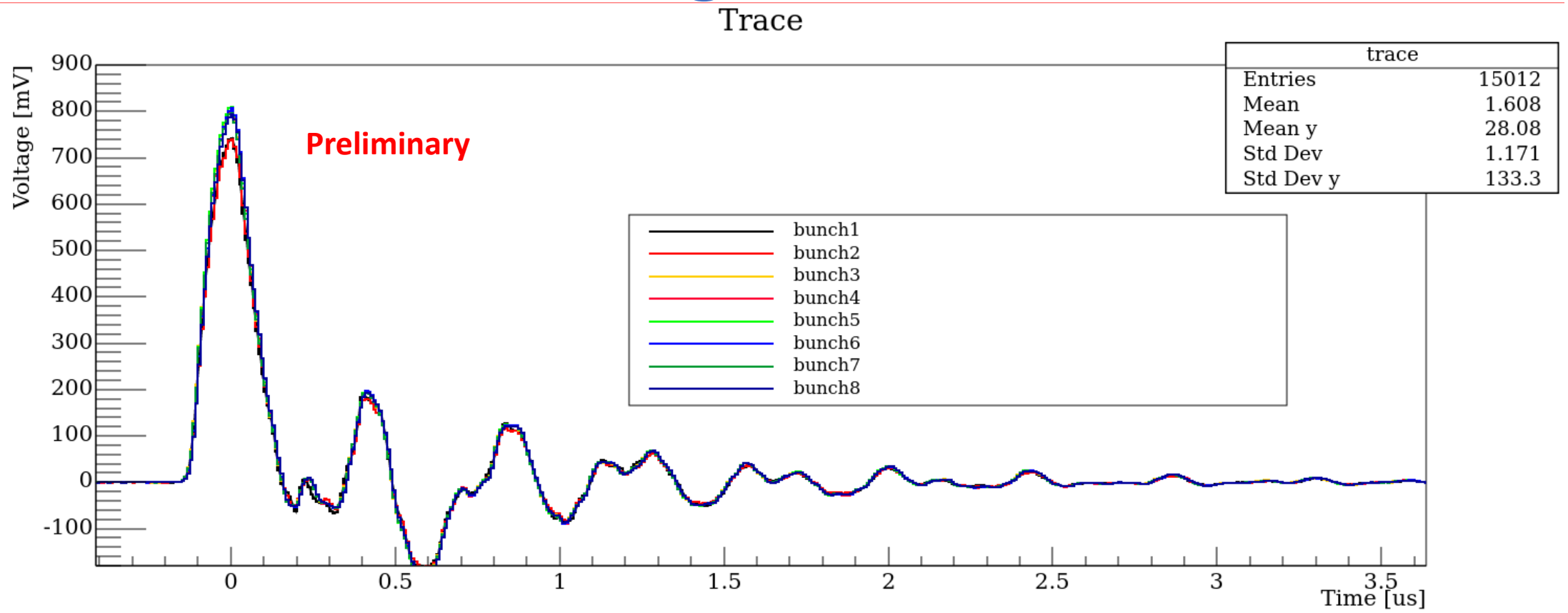
Probing the radial dependence of the kicker pulses





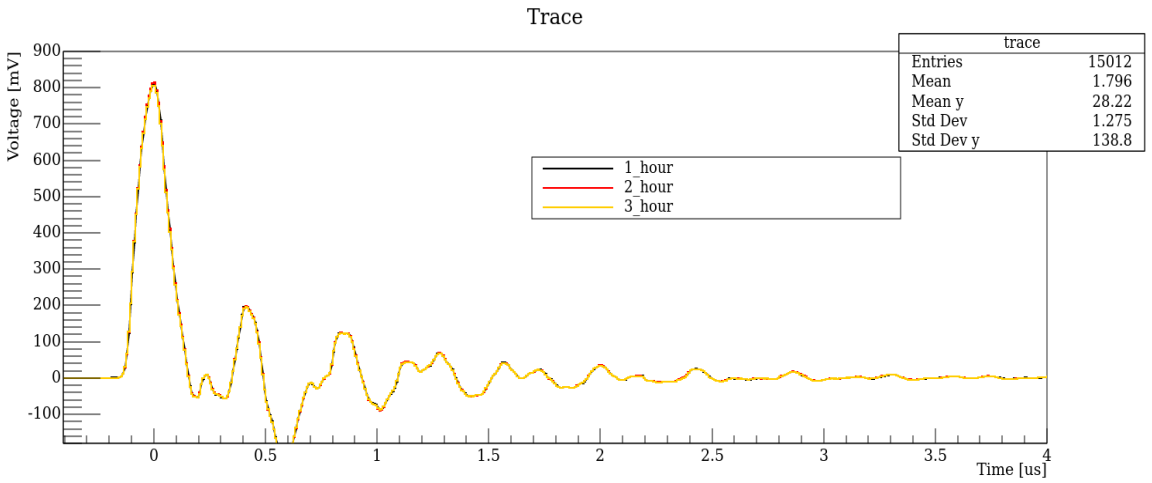
We have the possibility to acquire datas with a different radial distance than the magical one, the second periscope is shifted 1.5 cm radial farther (R_1) than the central one (R_0)

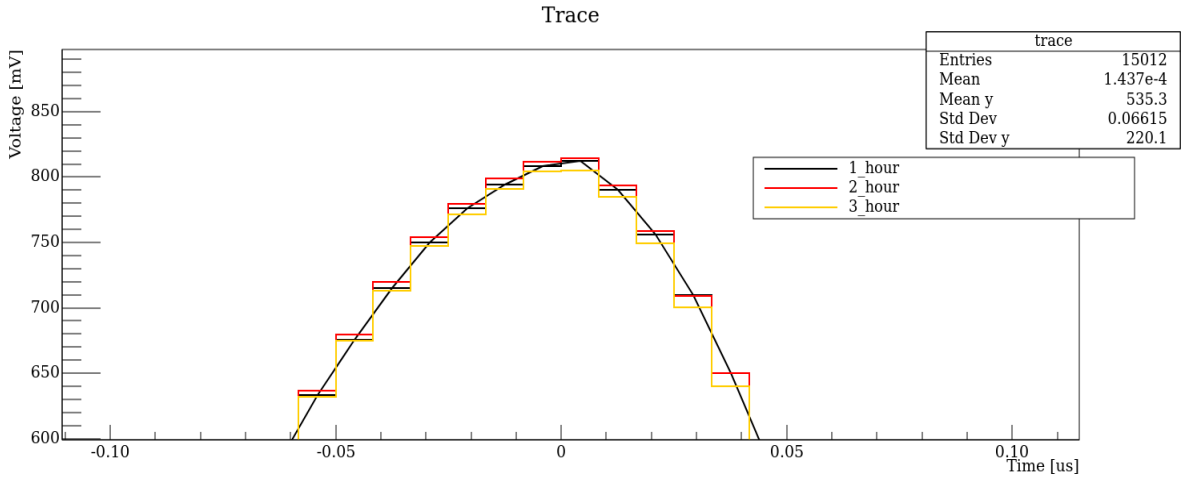
Kicker Pulse R0 Configuration

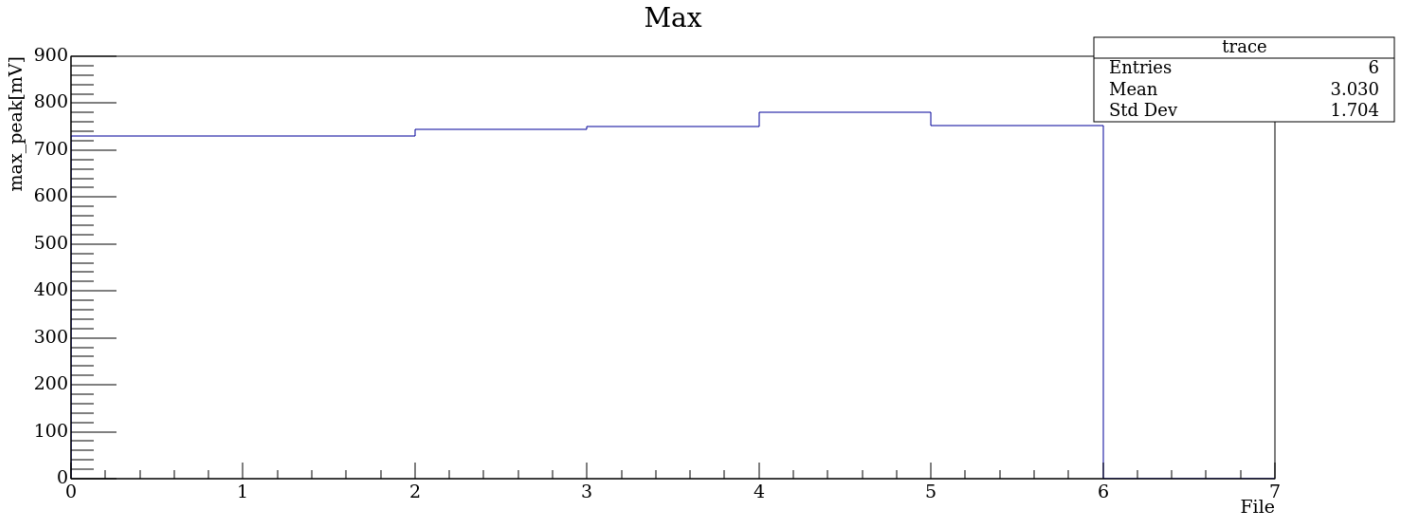


The strenght of the kick in 1st and 2nd bunch appears to have a lower amplitude than the other ones of a ~10% factor. ~~Still under investigation~~

Kicker amplitude differences investigation

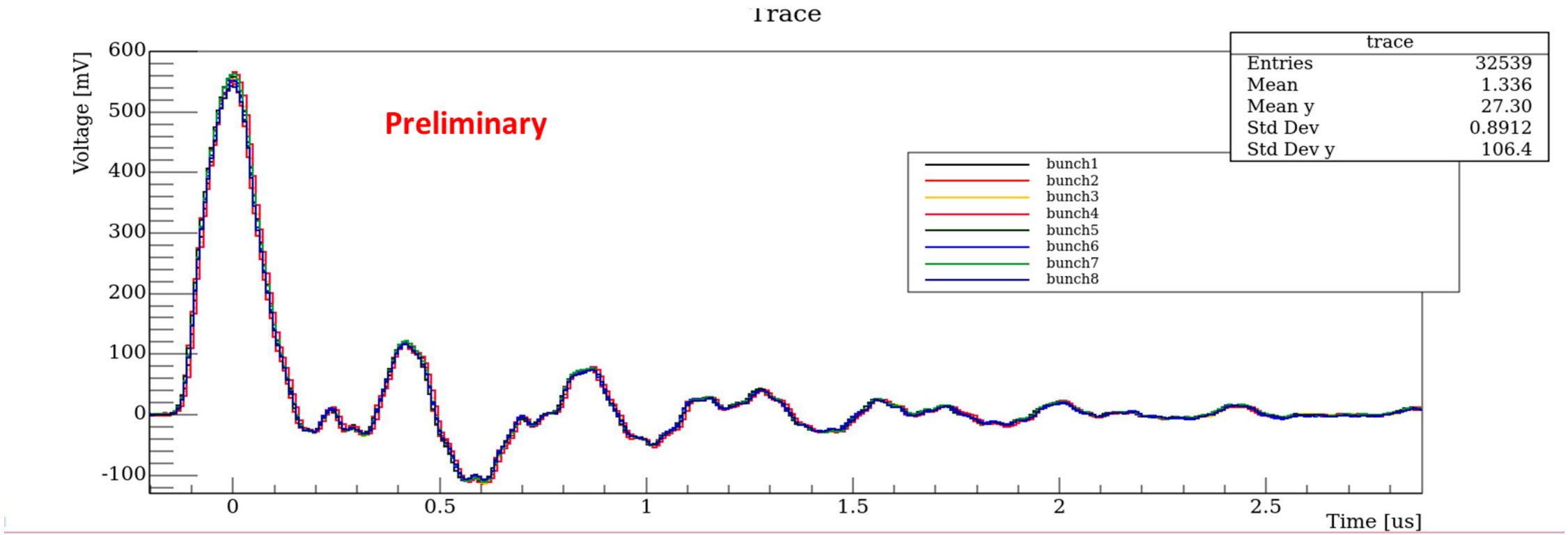






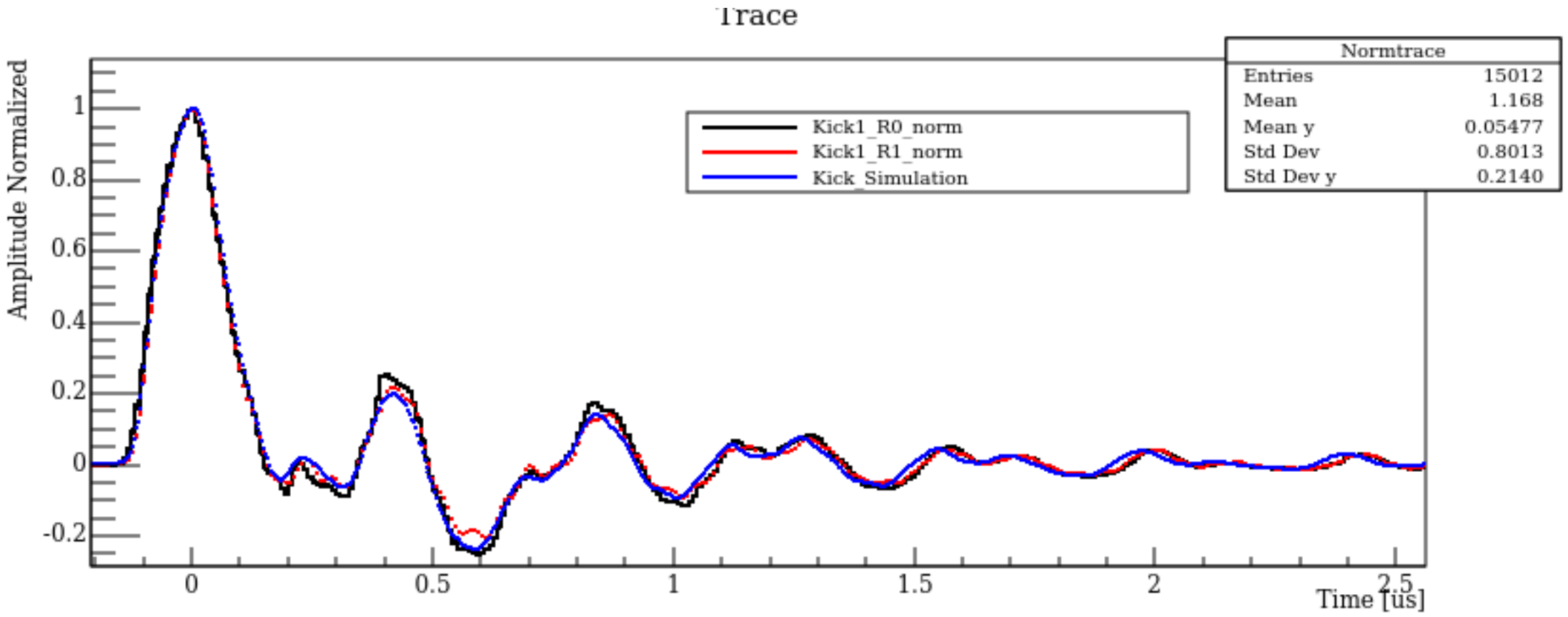
The reason for the lower amplitude of the first two kicks is probably the «heating time» of the kicker system.
More statistic would be needed to complete the study

Kicker Pulse R1 Configuration



All the pulses have compatible shape and amplitude

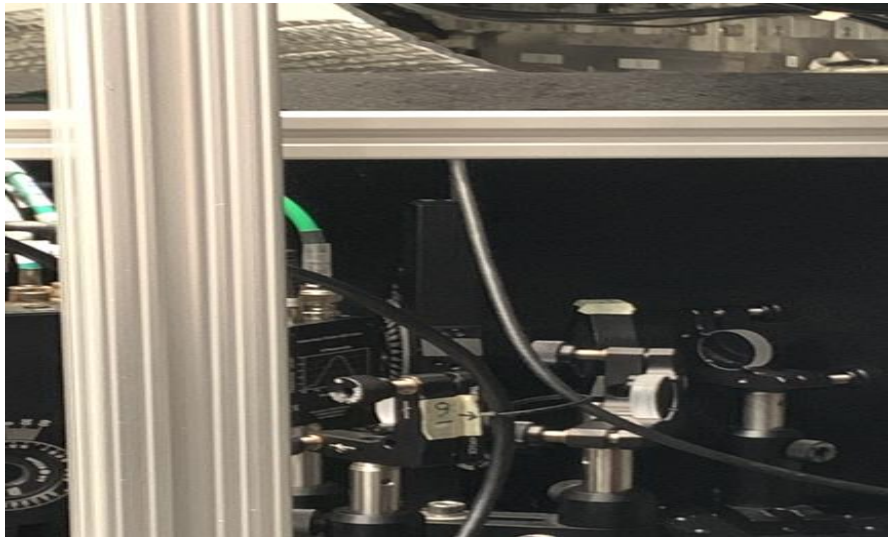
Simulation Kicks Comparison

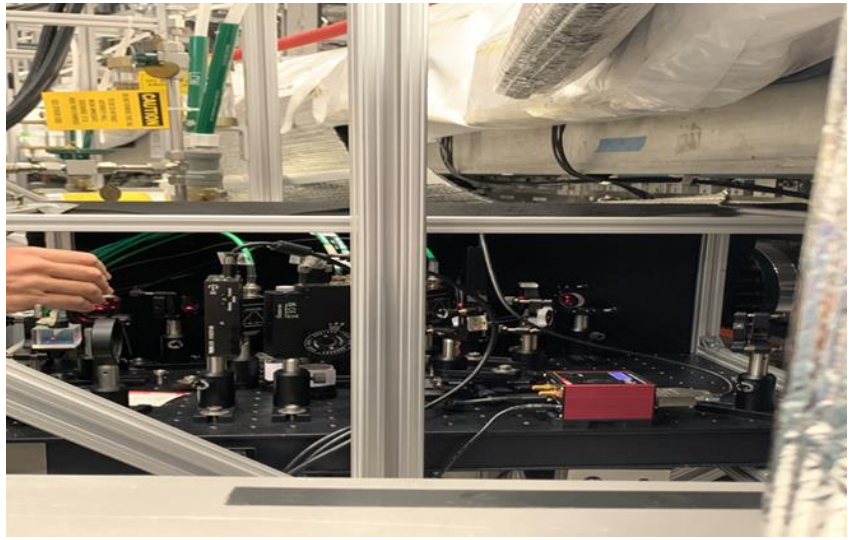


Both R_0 and R_1 normalized 1st kick have the same shape with the kick used in simulation. It confirms the pulse we are using in the simulation is corrected

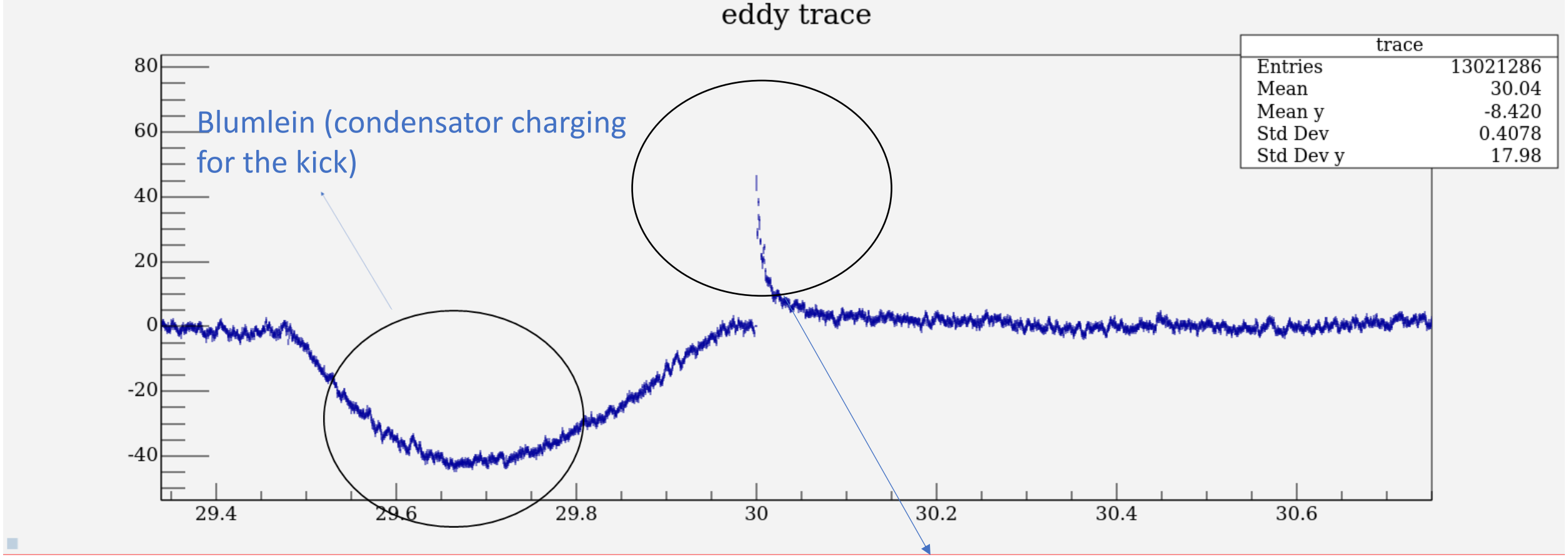
Magnetometer setup for eddy currents effects

- Add a lense to focus the laser on the photodetector
- Change the photodecter because for this measurement is needed an amplification of the signal
- Data were acquired in both configuration R_0 e R_1
- Each measurement was about 1 day long to minimize the noise



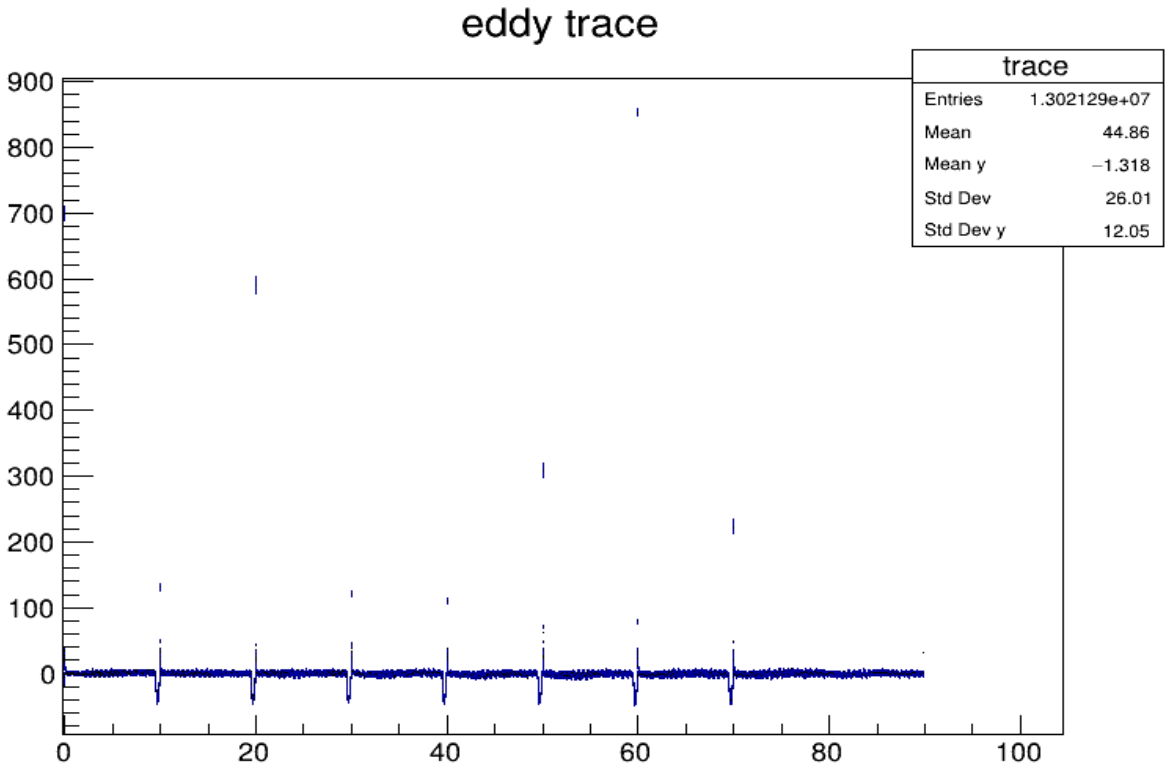


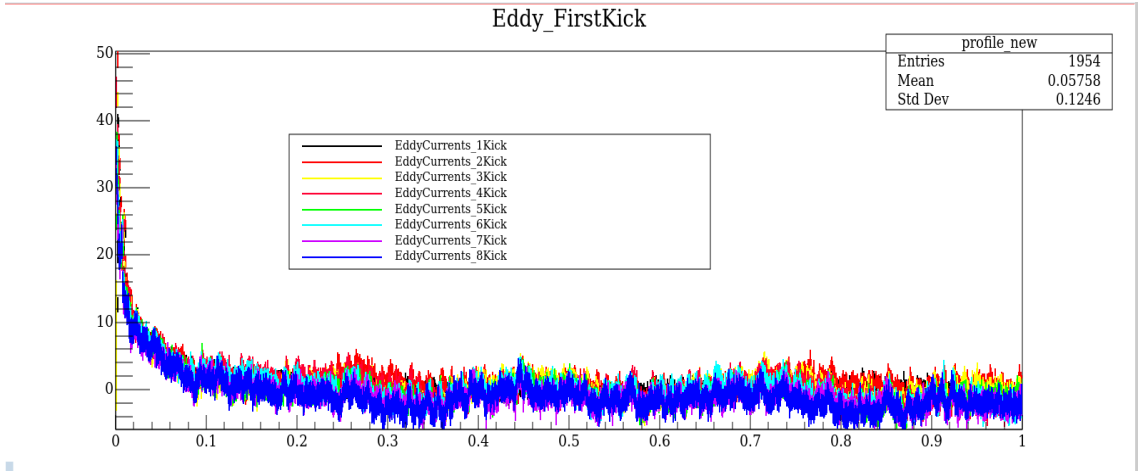
Example of an eddy currents plot

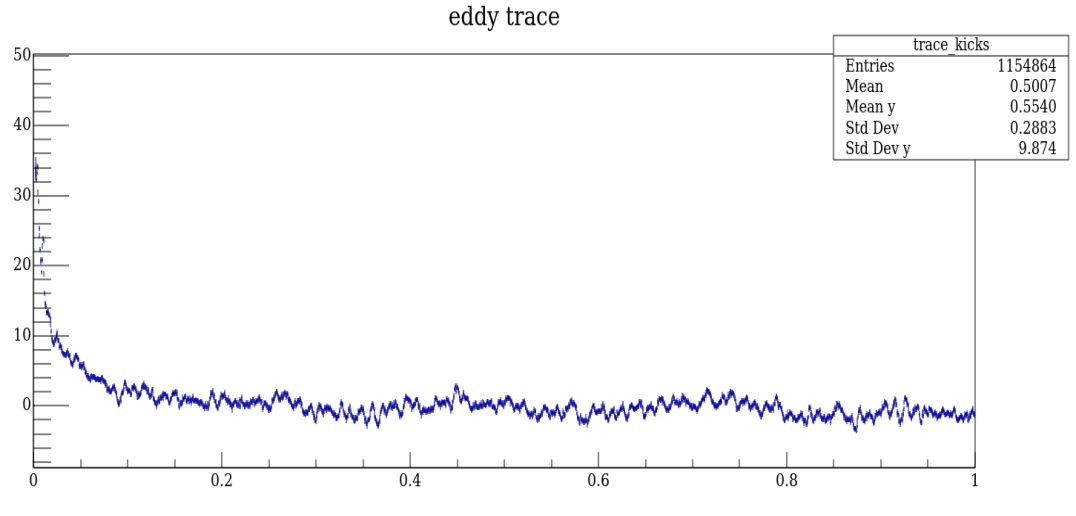


Analysis done for data taken in R_1 configuration

8 kicks plot in (0, 100)ms interval

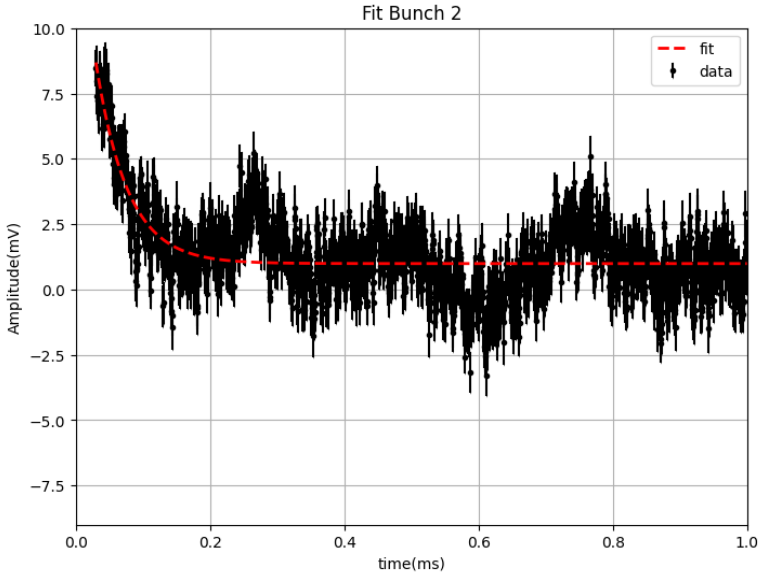


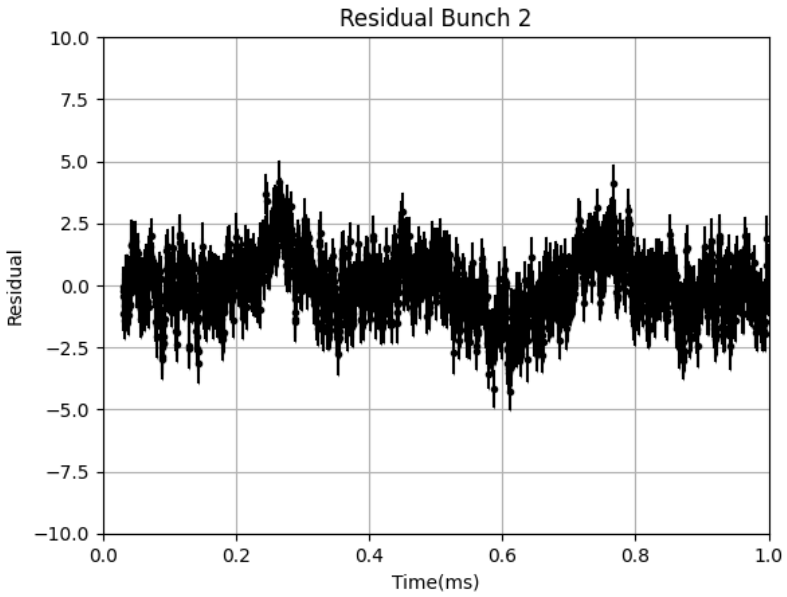


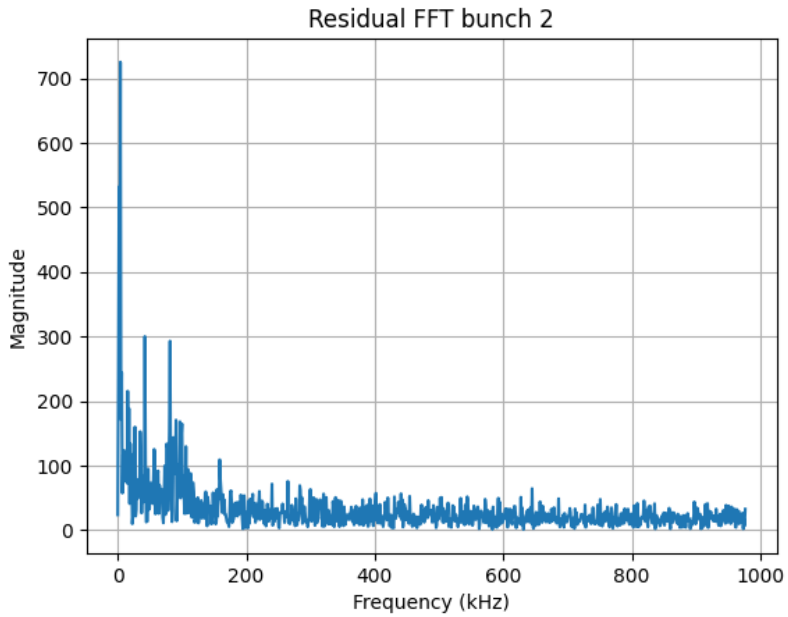


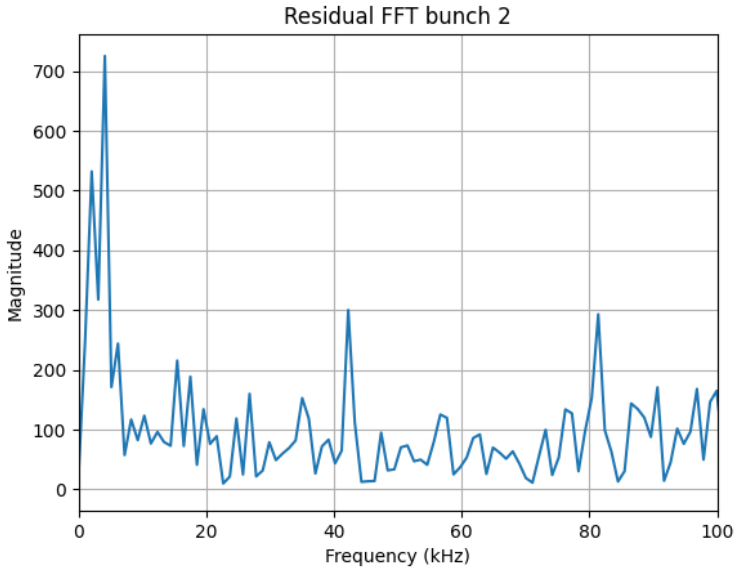
One kick every 10ms, all signals can be compared so the average has been done. The eddy currents effect could be described by an exponential behavior

Exponential fit is not enough…



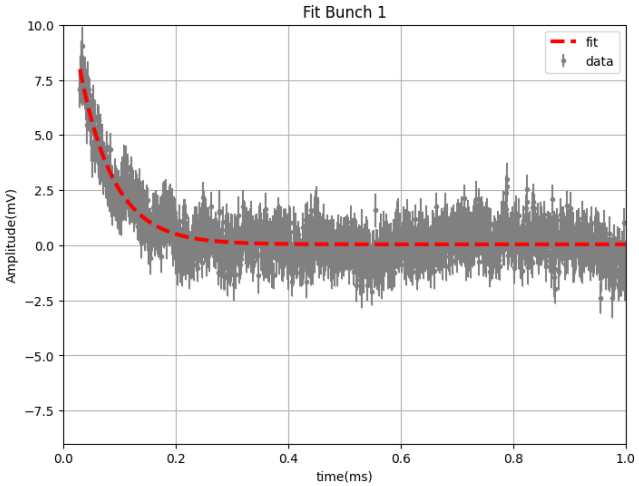


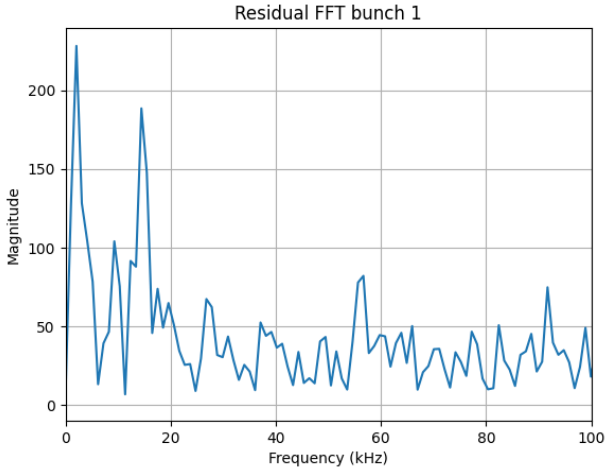


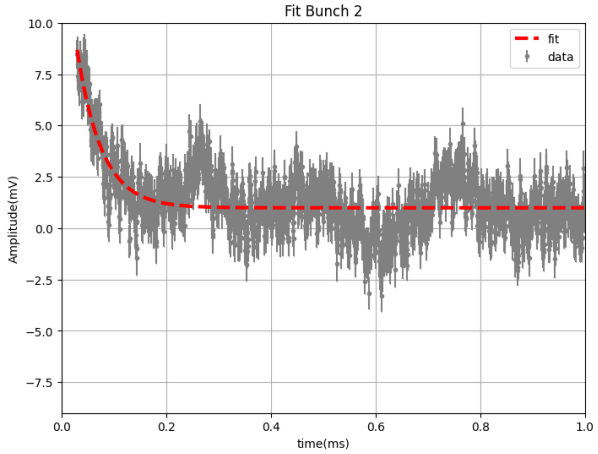


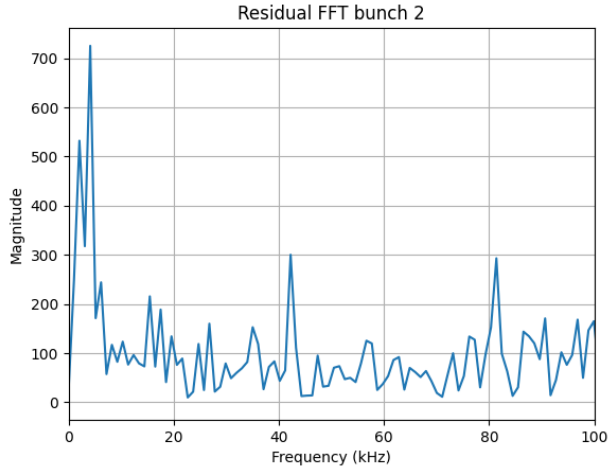
From the residual plot we see an oscillation and from the FFT plot we see at least three oscillations at frequencies of 3.8 KHz, 2.8 KHz and 17KHz probably generated by mechanical and electronical noise

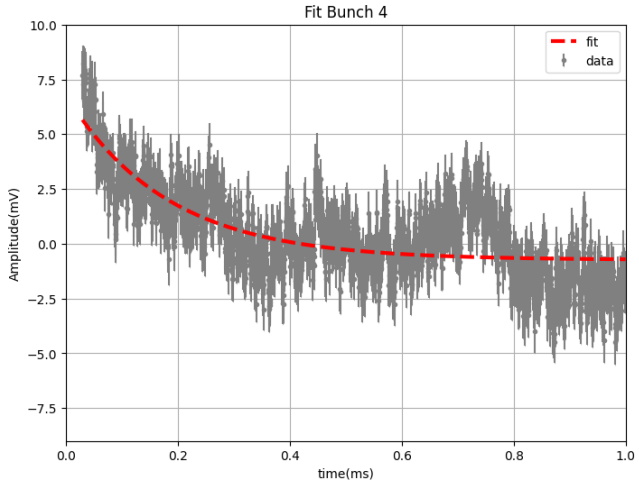
Exponential Fit and FFTs

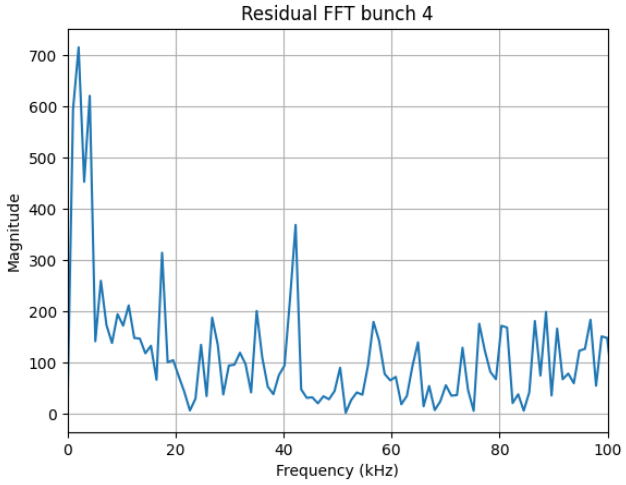


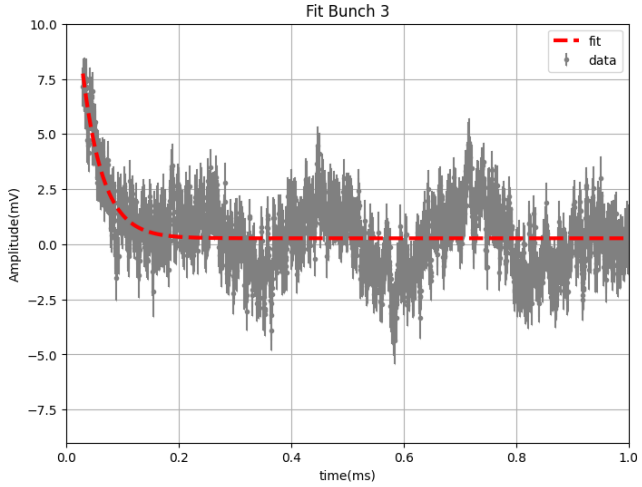


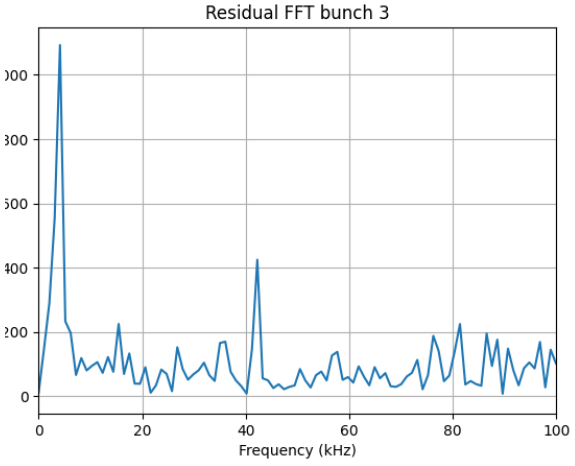




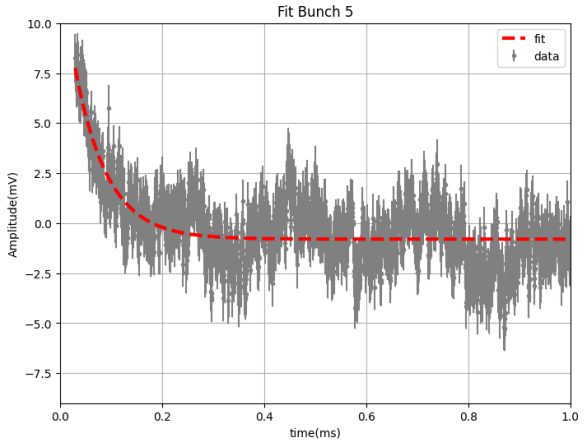


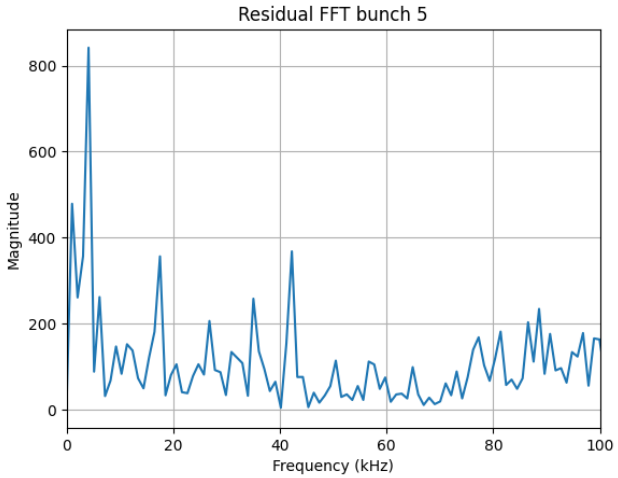


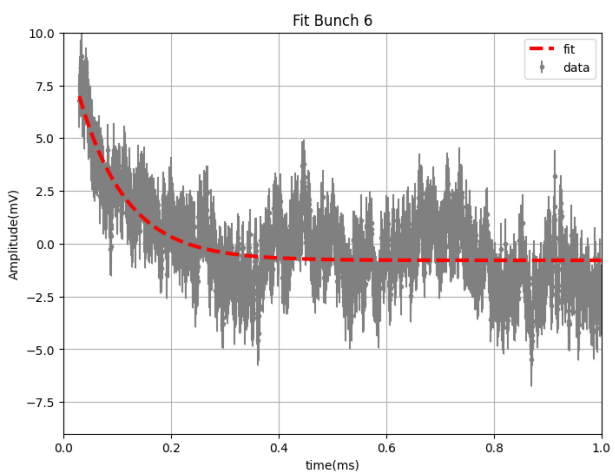


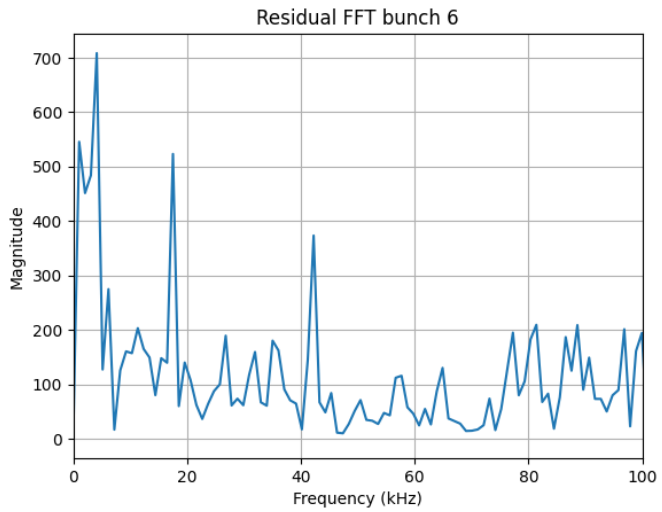


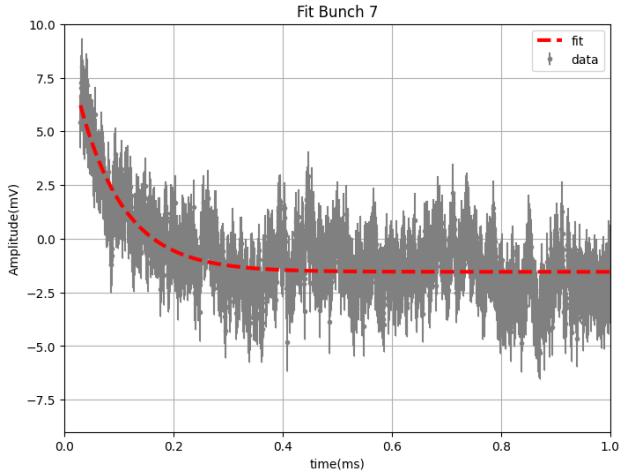
Exponential Fit and FFTs (part2)

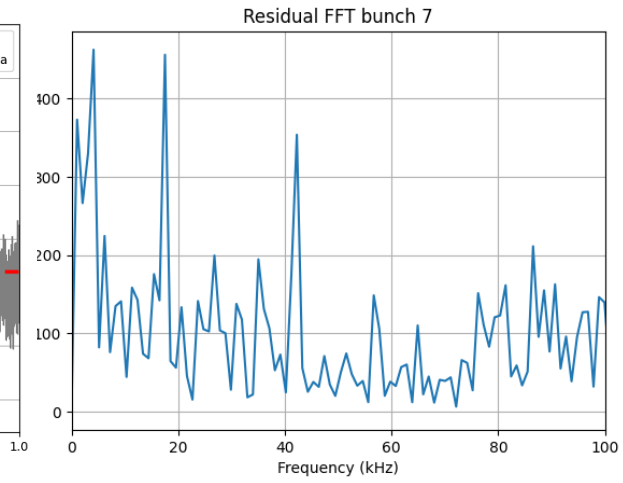


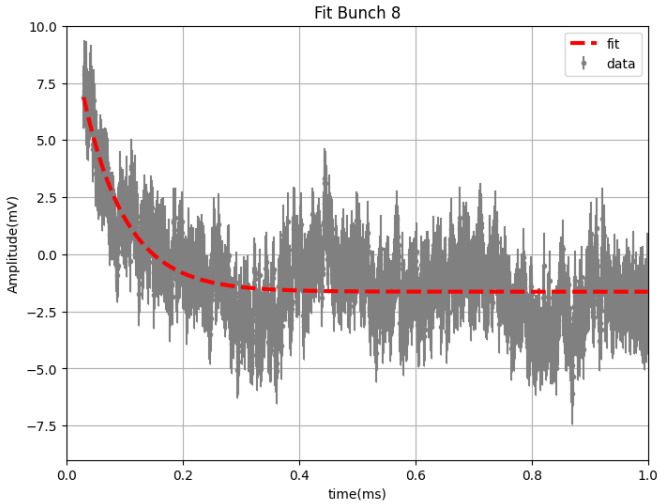


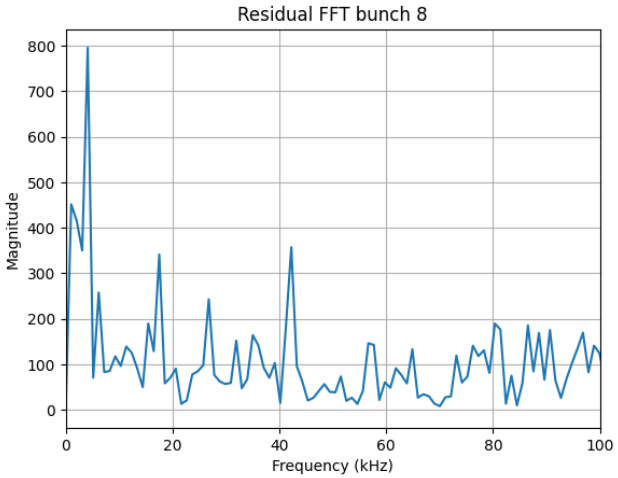




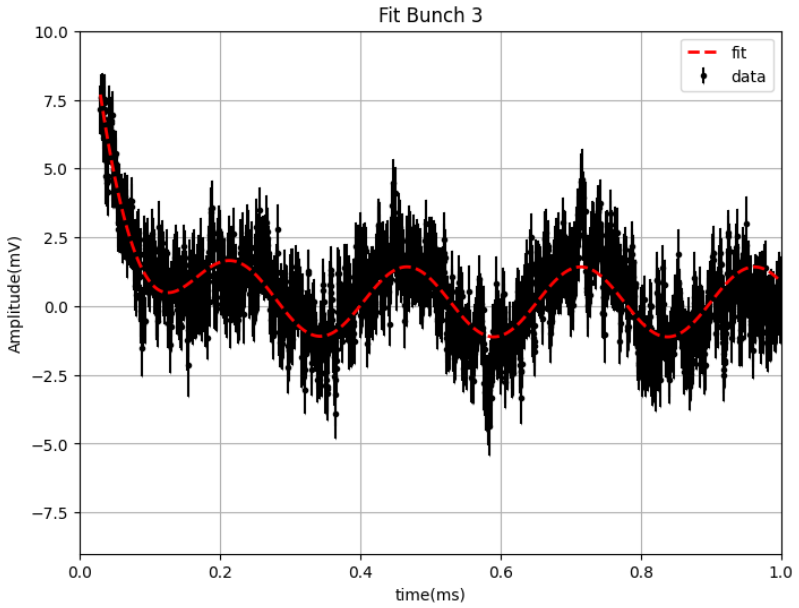


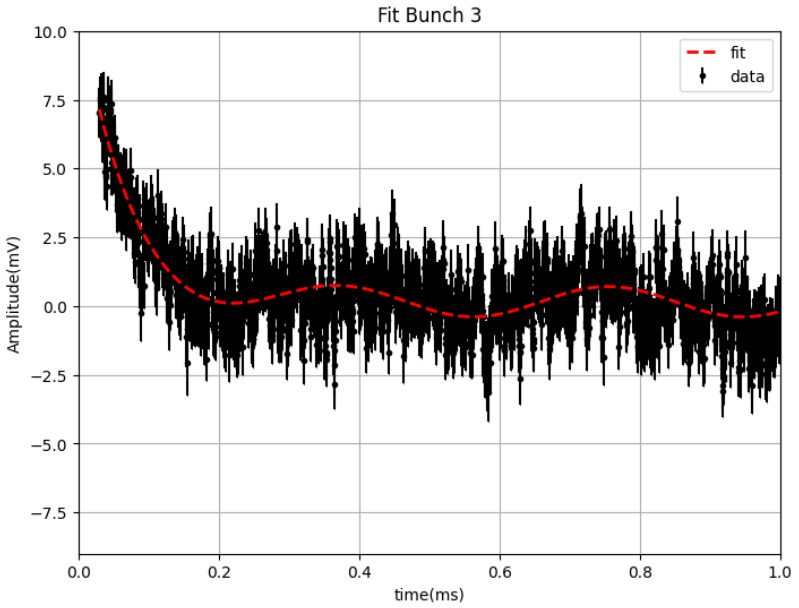


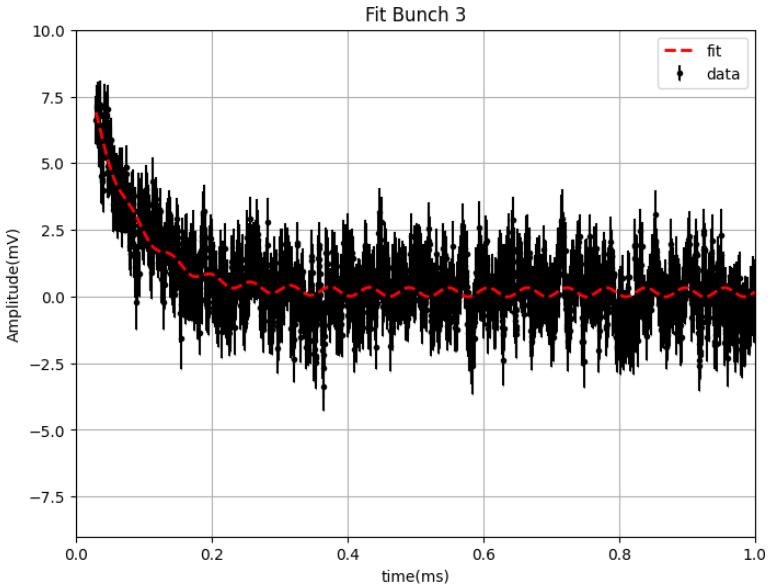




Oscillations in the bunches







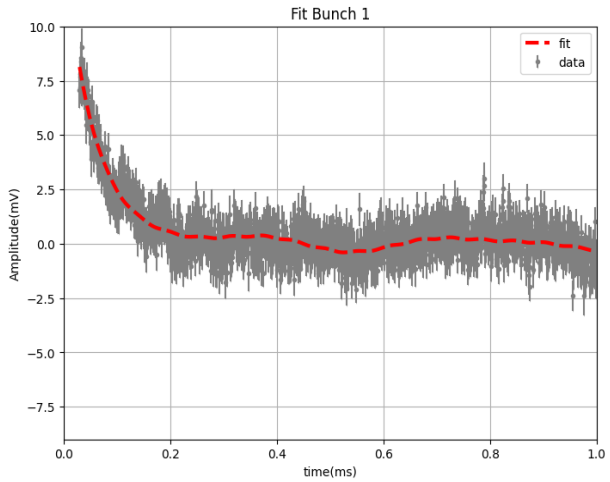
w≃1.9 KHz: Detector Mechanical Noise, probably generated by the breadboard vibrations since we see it in all the bunches

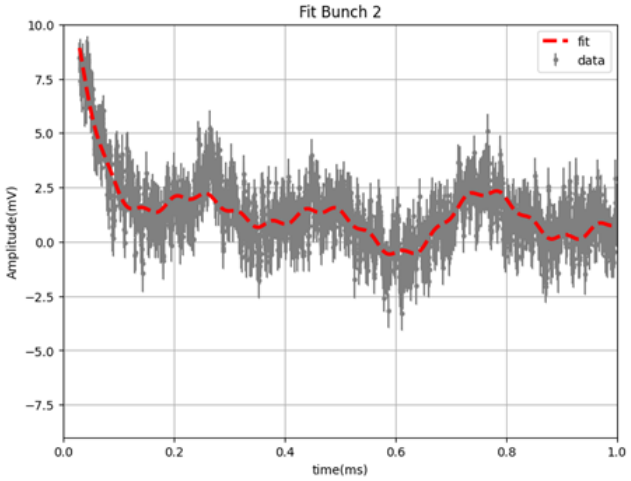
ω≃3.8 KHz: Mechanical Oscillation, probably generated by periscope bridge vibration, caused by the previous kick arriving, since we do not see it in the first kick but in all the other ones

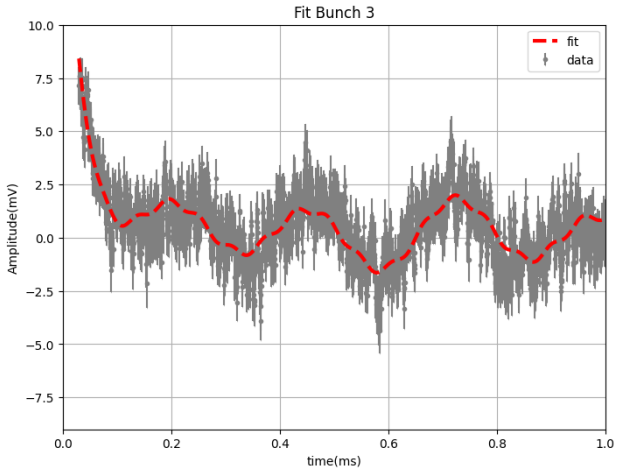
ω≃17 KHz: Kicker Field Oscillation, causing changes that needs to be accounted for magnetic field. This frequency has been seen also by the UMass magnetomer team with a fiber magnetometer.

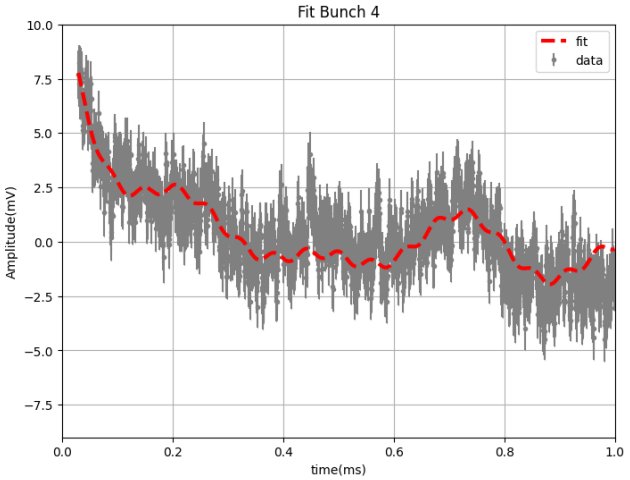
Total Fit on the 8 bunches

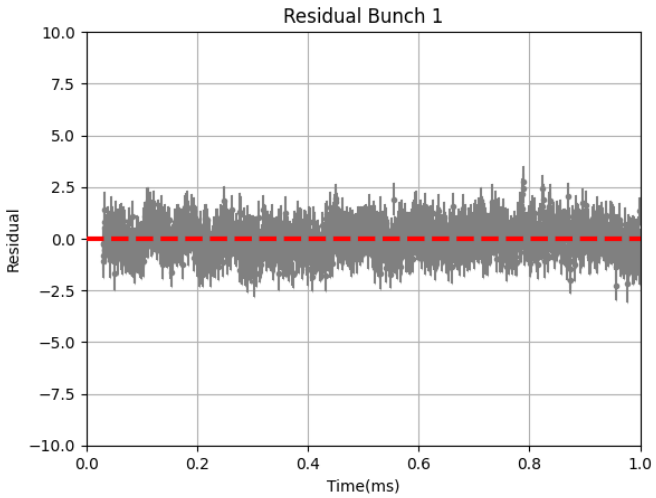
$$\left(\boldsymbol{Ae}^{\frac{-t}{\tau}} + \boldsymbol{B}\sin(\omega t + \varphi) + \boldsymbol{C}\sin(\omega_2 t + \varphi_2) + \boldsymbol{D}\sin(\omega_3 t + \varphi_3) + \boldsymbol{E}\right.$$

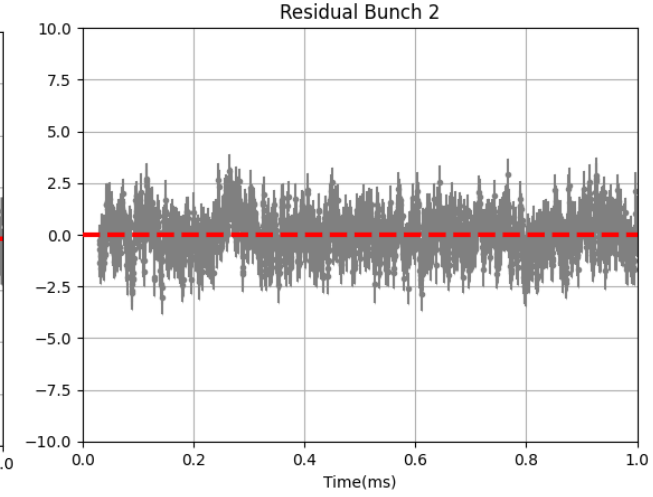


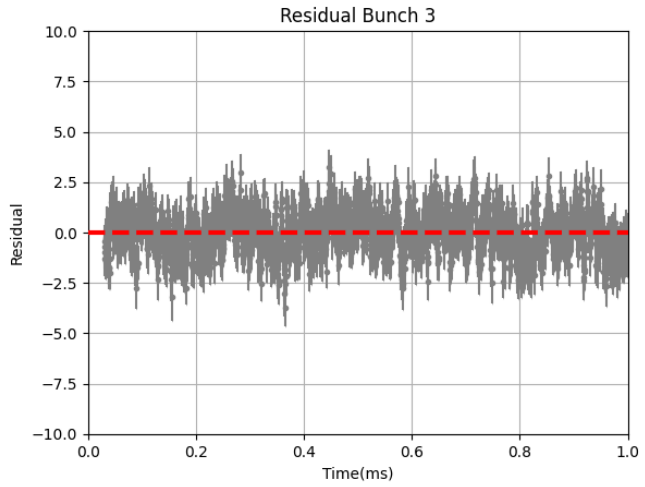


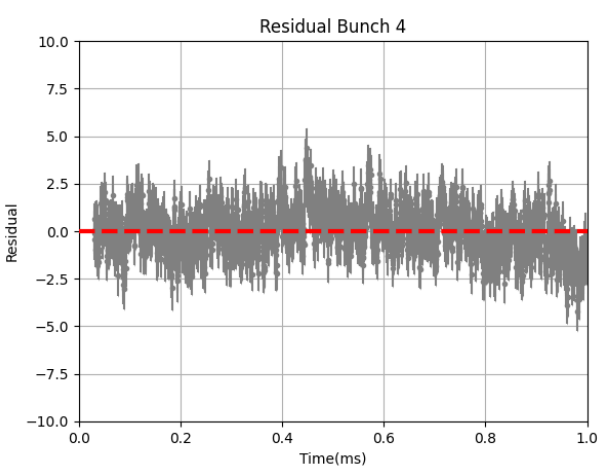




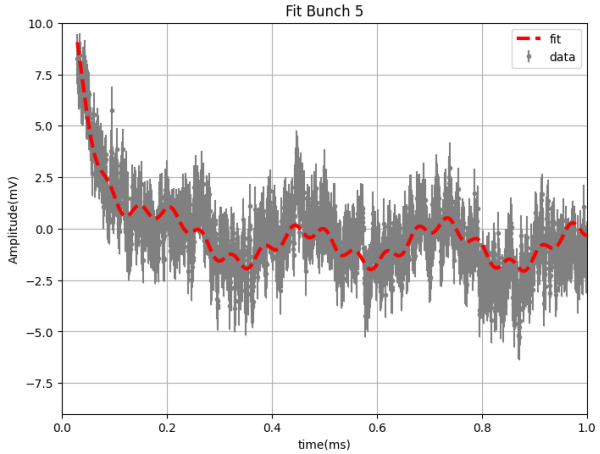


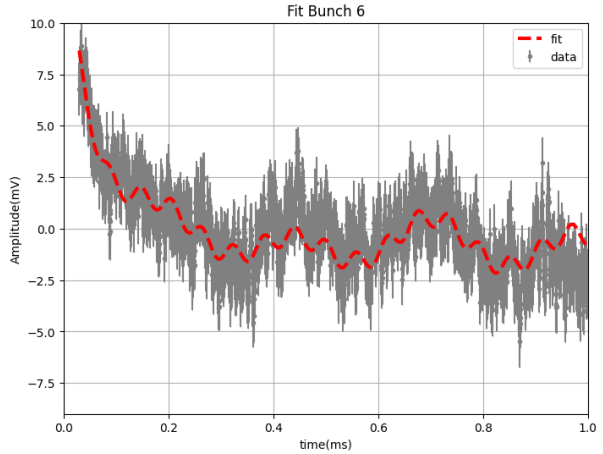


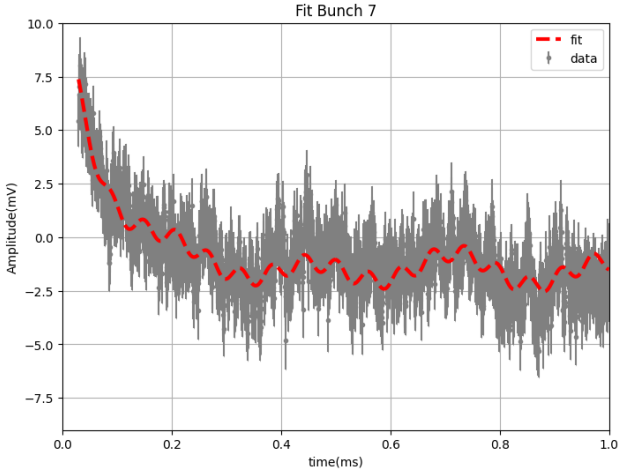


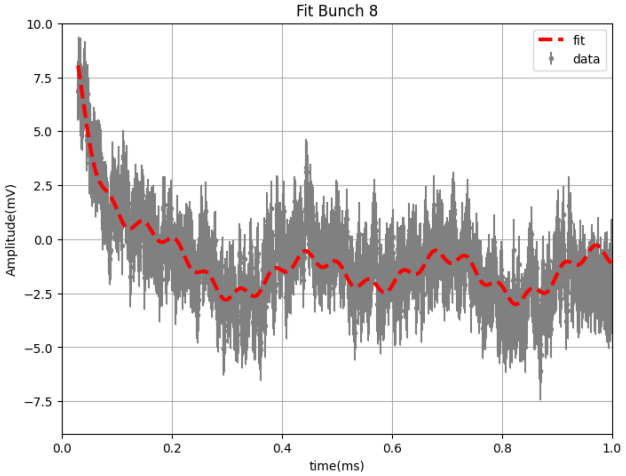


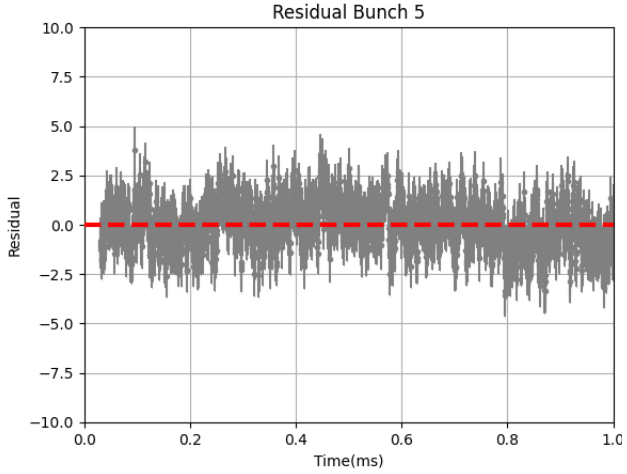
Total Fit (part2)

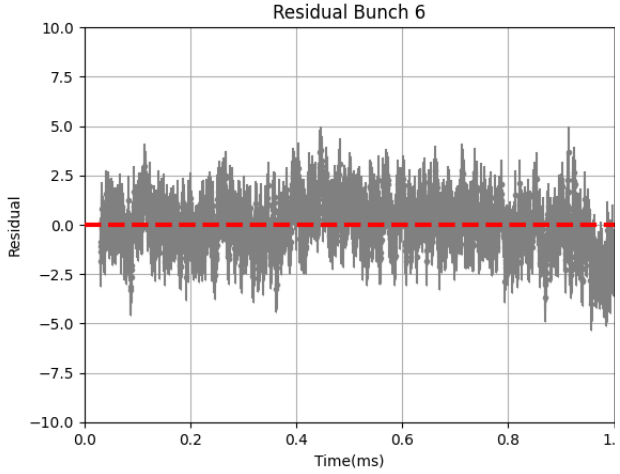


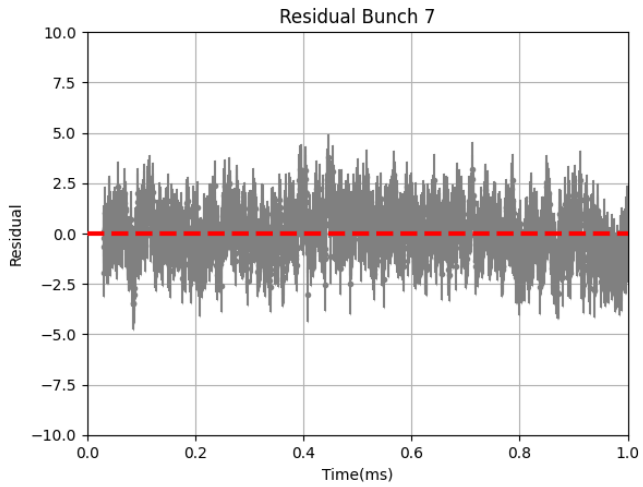


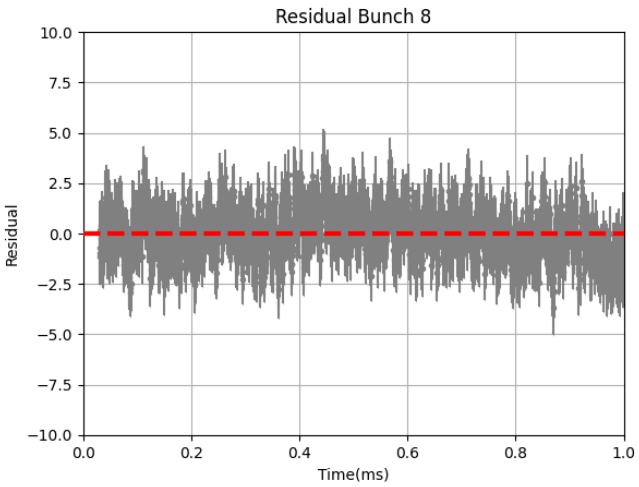




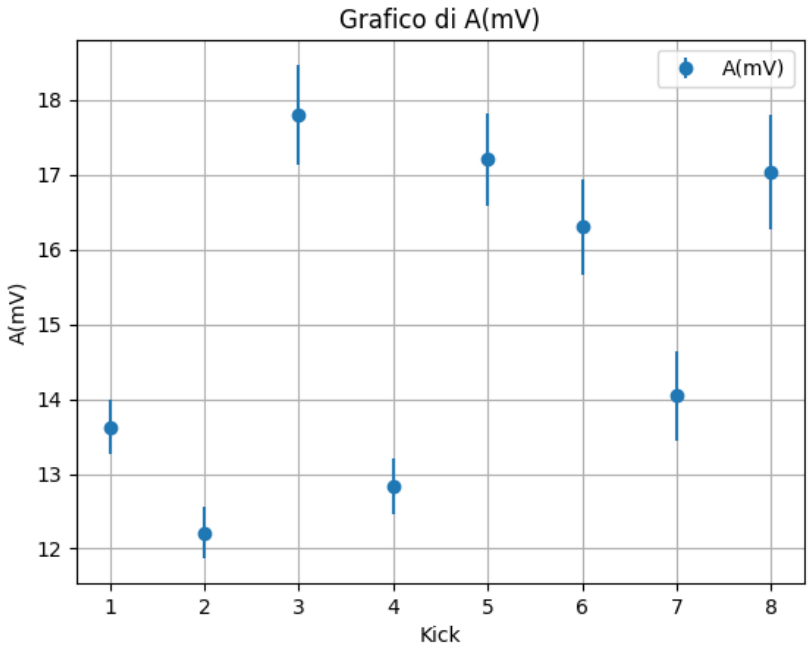


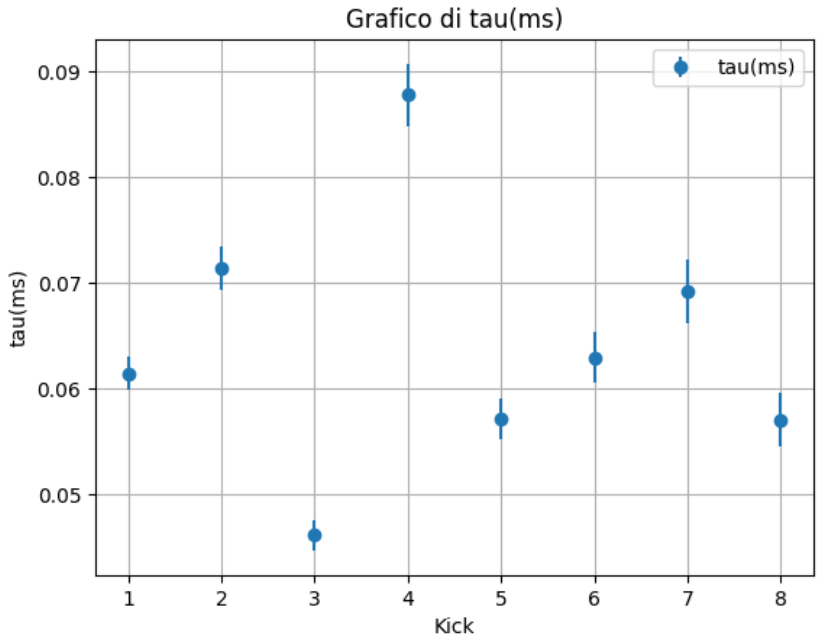


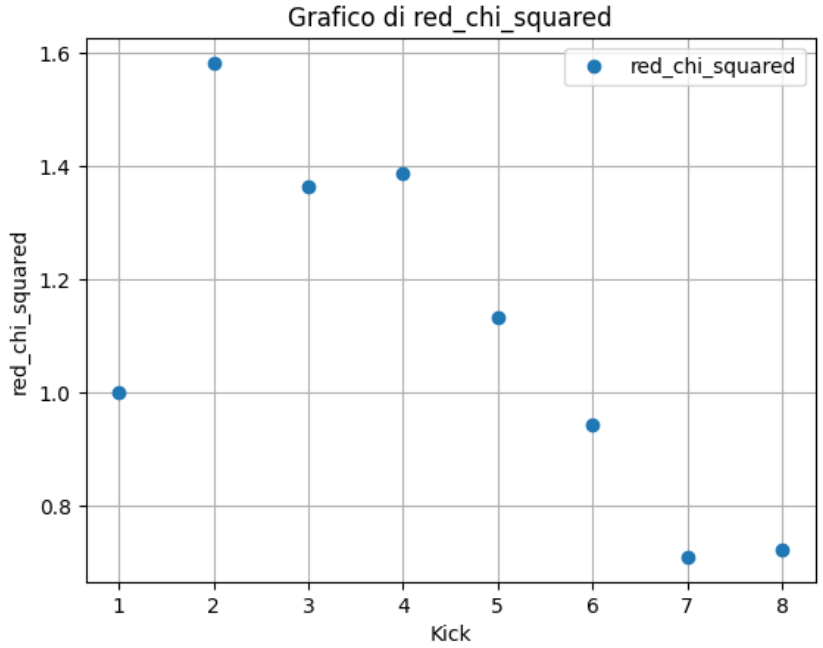




Fit Results



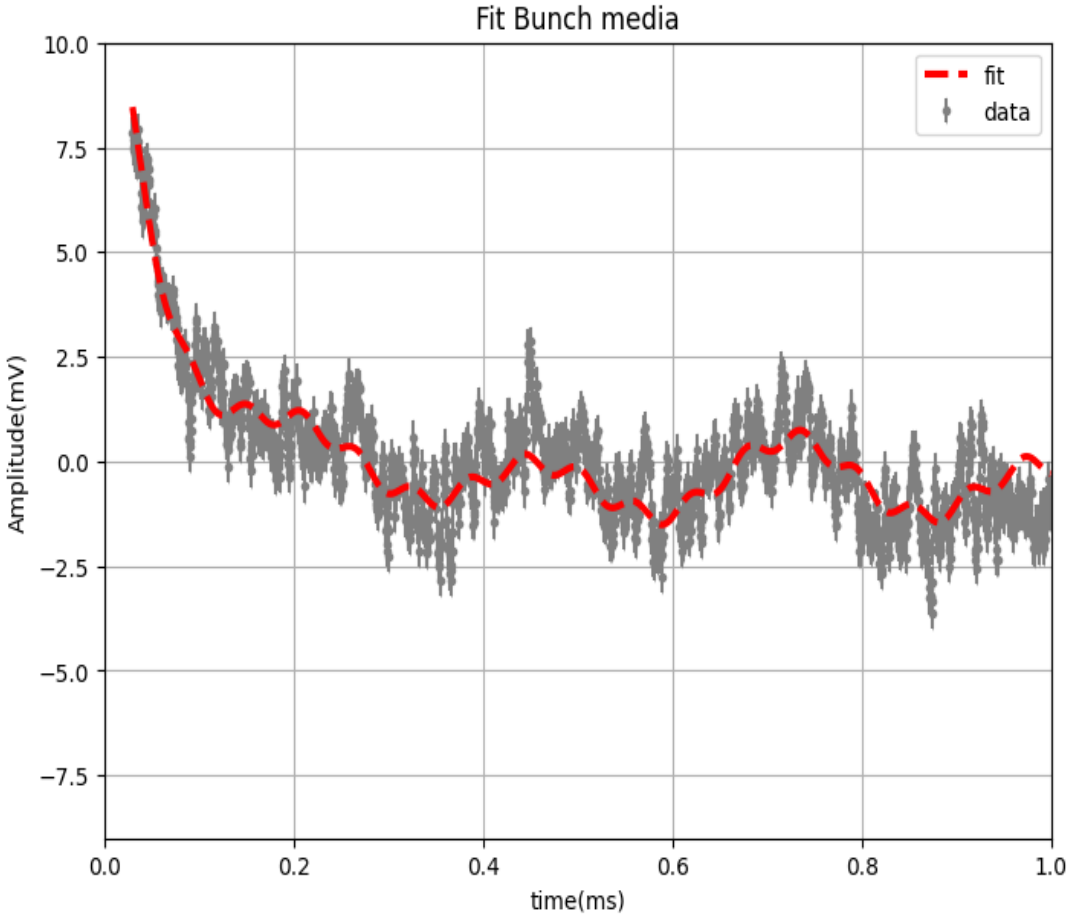


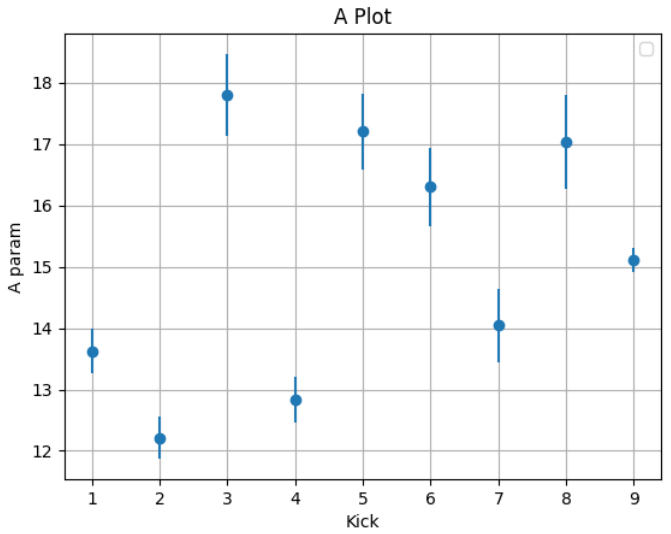


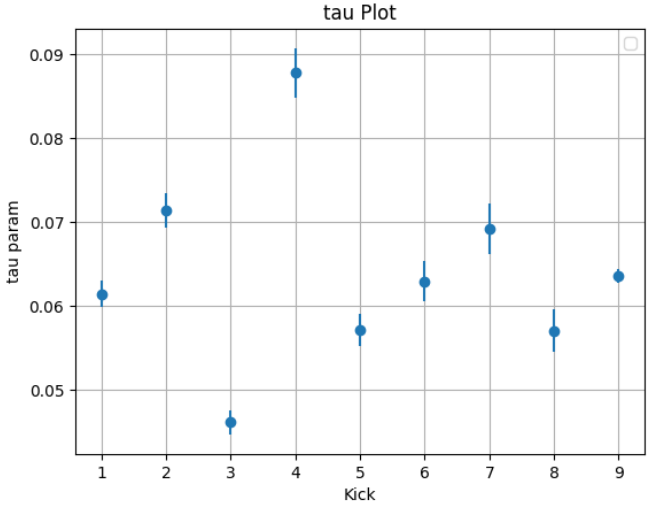
Kick4 τ and Kick3 τ are much different than the other ones and there seems to be a correlation between τ and A(exponential amplitude) values, the fitting function and the fitting parameters still need to be optimized

Total Fit on the 8 bunches

$$(\boldsymbol{Ae^{\frac{-t}{\tau}}} + \boldsymbol{Bsin}(\omega \boldsymbol{t} + \varphi) + \boldsymbol{Csin}(\omega_2 \boldsymbol{t} + \varphi_2) + \boldsymbol{Dsin}\,(\omega_3 \boldsymbol{t} + \varphi_3) + \boldsymbol{E}$$







From the fit on the mean plot the results obtained are:

- $A = (15{,}1 \pm 0{,}2)mV$
- $\tau = (0{,}0635 \pm 0{,}0007)ms$

Kick 9 = Average Kick

Next Analysis Steps for the final report

- Trying another fit with decaying 17KHz oscillation
- Compute the same analysis in R_0configuration and compare the results

Thanks for the opportunity to be at Fermilab. Thanks to Anna Driutti, Alberto Lusiani, Marco Incagli, Renee Fatemi, the simulation and magnetometer team, Hogan Nguyen and the Ops team in MC1 for all the help given!